SOUND

AND ITS

PHENOMENA.

Ebenezer BY Cobham

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Dedication.

TO THE

RIGHT HONOURABLE THE

DOWAGER COUNTESS OF ELGIN.

MY DEAR COUNTESS,

The frequent honour I have enoyed of meeting at your house the literary *élite* of various nations, and the great interest you always manifest in the subject of science, induced me to solicit the favour of dedicating to your Ladyship a series of Lectures, the first of which embraces the interesting subject of "Sound and its Phenomena."

I have the honour to be,

My dear Countess,

Your faithful and

Humble servant,

E. COBHAM BREWER.

PREFACE.

The extraordinary success which has attended the publication of the "Guide to Science" in the British dominions, America, and France, suggested to its author the probable acceptability of a series of lectures on Common Phenomena adapted especially to schools, the industrial classes, teachers, and the mothers of families.

The first of this series is now published under the title of "Sound and its Phenomena." Great pains have been taken to preserve such simplicity of language and perspicacity of explanation as can alone commend the book

to the numerous classes for whom it is designed. The second number, on "Heat and its Phenomena," is nearly complete; and it is intended that the entire work should furnish a satisfactory scientific elucidation of every common phenomenon, whether of a physical or chemical character.

Any suggestions or observations which may be useful in the prosecution of this design, sent to the publishers under cover to the author, will be gratefully accepted and duly considered.

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SOUND AND ITS PHENOMENA.

CHAPTER I.

THE CAUSE OF SOUND.

INTRODUCTION.

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INTRODUCTION.

THE science of acoustics* is a part of physics which embraces whatever pertains to the cause, the nature, the sensation, the phenomena, and the laws of sound. It shows how it is produced and what physical changes take place in order to produce it. It explains how it is communicated to the air, how it is propagated through different media, and how the sensation is registered on the organ of hearing. It treats of music so far forth as that science is connected with physics;

* Acoustics, from the Greek ἀκουστικος, or from the verb ἀκούειν, *to hear*. The science is sometimes divided into *Diacoustics*, or the transmission of sound through different media, and *Catacoustics*, or the phenomena of sound.

embraces in its range the mystery of echo; anatomises the curious workmanship of the ear; pries into the mechanism of the voice; and explains how buildings should be constructed so as to prevent the transmission of sounds into contiguous rooms, and so as best to favour the orator and the musician.

The science of Acoustics forms a part of physics, because all bodies from which sound is proceeding experience at the time a physical disturbance wholly the result of physical force.

PROP. I. SOUND AN EFFECT OF MOTION.

1. A *cup and saucer*, or a *metal tray and snuffers*, left on a pianoforte while a person is playing, will *jingle* or *rattle* from the physical effects of the music.

Rattling of snuffers from music.

2. *Sand* strewed on a piano, or on the sounding-board of a violin, will be *agitated* immediately a note is struck on these instruments.

Sand agitated by music.

Water agitated by music.

3. *Water* contained in a glass will exhibit a *trepidation*, or kind of *simmering*, when a person touches the rim and makes it ring.

Church benches shaken by music.

4. Every one must have occasionally remarked that the *benches of a church tremble* from the deep notes of an *organ;* and that a similar motion is not unfrequently produced in a concert-room from the forcible notes of a double-bass or of a kettle-drum.

Rattling of windows.

5. The *rattling of windows* when carts pass by is a striking instance of the agitation produced by sound. This phenomenon is wholly due to the shock of sound-waves against the exterior surface of the window-panes, and the impulse is, in some cases, sufficiently violent to make the glass ring and the frames tremble. When carts heavily laden roll along a street, or others of lighter freight pass with considerable velocity, the *momentum* of the sound-waves is frequently

so great as to shake the solid edifice and make the chairs and tables tremble.

6. In large cities of great traffic the physical disturbance thus produced on slimly-built houses is no inconsiderable cause of their rapid decay.

Street sounds injure houses.

7. A peal of thunder and an explosion of gunpowder produce an agitation still more perceptible. It may, therefore, justly be inferred that sound and motion are in some way connected; and, since sounding-bodies produce this agitation only when they are giving forth sounds, we may conclude that *sound is an effect of motion* of some sort or another. The exact nature of this motion remains to be now investigated.

Sound the effect of Motion.

PROP. II. THE MOTION WHICH PRODUCES SOUND IS ALWAYS VIBRATORY.

8. This proposition will be by no means difficult to prove. A harp-string struck by the finger

Sound of harp-strings.

will swing backwards and forwards for a certain time, producing a sound as long as the vibrations continue.

Cry of a quill.

9. Similarly, a pen, or piece of quill, or morsel of steel-wire, held between the teeth, will utter *a sound* as often as the extreme end is inflected.

Vibrations of a tuning-fork felt.

10. By touching your teeth with one of the prongs of an excited tuning-fork, you may even feel its vibrations.

In all these cases the motion of the sounding-body is manifestly a *vibratory motion*. Let us take another example.

Vibrations of a bell.

11. After having struck a large *bell* or glass, allow a *pith-ball*, attached to a piece of cotton, to touch the sides in any point whatsoever, and mark how it will behave. It will first be violently repulsed, then fall back again by its own gravity, be again repulsed, and will again fall upon the sides of the bell or glass to experience another repulsion.

12. We therefore conclude not only that *motion* is the cause of sound, but that the nature of such motion is *vibratory*. Sound produced by vibrations.

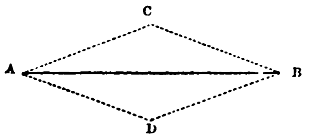
PROP. III. THE PRESENCE OF SOME ELASTIC MEDIUM ESSENTIAL TO RENDER SOUNDS AUDIBLE.

13. If a bell properly isolated* be rung in the exhausted receiver of an air-pump, *no sound whatsoever* will transpire. Without doubt, therefore, the presence of air, or of some other elastic medium, is in *this* case essential to render the sound of the bell audible. What is true of the bell in the experiment referred to, is equally applicable to sounds in general; there must always be some uninterrupted vehicle, or series of vehicles, between the sounding body and the listening ear, in order to produce the sensation of sound. Air essential to sound.

* The bell is isolated by being placed on a cushion of wool or cotton.

Nature of sound-waves.

14. The *nature of sound-waves* may be understood by the following illustration: suppose A B to be a harp-string. Let it be drawn by the finger up to C. As soon as it slips from the finger it will fly to D, on the opposite side of A B, then back towards C, and so on alternately till it becomes quiescent.



First, suppose it to swing from C to D, it is evident that in this march it must displace all the air between these two extremes, propelling it in the same direction, and, by the action of the impulse, *condensing* it also. The air thus dislodged must communicate its motion and condensation to the adjacent portion of air, this latter to a third, the third to a fourth, and so on indefinitely; the effect being always transmitted from the nearer strata to those more remote, until it ceases altogether.

While this is going on, the string bounds back again from D towards C, and makes room in the void thus created for the condensed air to *dilate.* This dilation is followed successively by every portion of air previously condensed, the result of which is a second series of ripples. In this way the air is condensed and expands alternately, producing a kind of tidal motion which circulates as far as the sound itself.

15. Immediately these ripples reach the ear, they beat against the tympanum, and communicate to it corresponding vibrations, which, being conveyed to the auditory nerve, produce the sensation of sound. Sensation of sound.

16. While a string vibrates rapidly, the whole field through which it passes seems enveloped in a white *haze* or mist, due to the following cause: the impression made by the string upon the eye continues after the string has passed from one part of its field of motion to another; Haze of vibrating strings.

so that the eye has not time to recover from one impression before another is produced. These several impressions coalescing fill the whole space, and produce the opacity referred to.

Misty appearance of wheels in motion.

The spokes of a rapidly revolving wheel give a similar *misty appearance* to the whole area of the wheel. A charred stick, moved rapidly backwards and forwards, produces the appearance sometimes of a ribbon, sometimes of a circle of fire.

17. All bodies may, by some mode of excitation, be made to produce sound, but there is a vast difference among them in the quality, intensity, and continuance thereof; those substances being most sonorous, and sustaining sound the longest time, which are most susceptible of vibration.

Sounds various.

18. The *character of sound* is chiefly determined by the form, magnitude, and density of the sounding-body, the method whereby it

is excited, and the comparat
of the power with which it
motion.

19. Sound-waves are engendered in the air by whatever gives it a sudden shock: as by the rapid impulses of some vibrating body; by a solid substance rapidly and suddenly changing its place; by the percussion of one stratum of air against another; or by a combination of some two or more of these collisions.

Causes of sound.

SEC. I. SOUND-WAVES PRODUCED BY THE AGENCY OF VIBRATING BODIES.

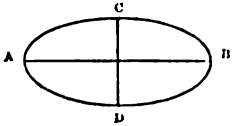
20. When a BELL is struck by its clapper a sound is produced, because the blow disturbs the repose of the part struck. This disturbance spreads rapidly throughout the entire bell, the walls of which flatten in one direction and elongate in another. Being elastic, the two parts bound back and fly to the opposite extremes; so that the circumference of the bell

A bell.

assumes an elliptical form, in whic the longer and shorter axes alternatel interchange.* As the flattened pa elongates with a sudden impulse, i gives the air a shock, compresses it, an drives it *away from the bell.* A serie of condensations are thus establishe which propagate themselves from th portions of air adjacent to those mor remote. In the mean time, the pro truding part of the circumferenc flattens, the air which was previousl condensed *dilates*, and forms anothe series of motions of the same extent bu of an opposite character to the former and these two series are renewed s long as the bell continues to sound.

Sound spreads in cs.

21. The sound-waves thus create diffuse themselves in concentri circles around the point of thei birth, not unlike the ripple



* Let the oval figu A C B D be an ellipse; the A B is its longer or *maj axis*, and C D its shorter *minor axis.*

made by a stone when it falls intc tranquil water.

22. The sounds which proceed from all stringed instruments of music, such as pianofortes, violins, violoncellos, guitars, and harps, are due to the agency of vibration; those also of the Jews'-harp and musical snuff-box; and those of all instruments which *ring*, such as bells, musical glasses, tuning-forks, cymbals, and triangles.

SEC. II. VIBRATIONS ENGENDERED IN THE AIR BY THE MOTION OF BODIES WHICH DO NOT THEMSELVES VIBRATE.

Whizzing of projectiles.

23. The WHIZZING of a BULLET, cannon-ball, or arrow, flying through the air, arises from the inequalities of their several surfaces; in consequence of which, they resent to the air at equal intervals me protuberance or roughness first one side and then to another. By ese constant shocks the air is made to sume a vibratory motion; and as they

succeed each other with great rapidity, making a new impression on the ear before the preceding one is effaced, the sound appears unbroken or continuous.

Hum of a peg-top.

24. The HUMMING of a PEG-TOP arises also from the *inequalities of its surface*, which, so long as the gyrations are very rapid, give the air a succession of little shocks sufficiently violent to create sound-waves in that subtile element.

Spring-rattle.

25. The noise of a SPRING-RATTLE is occasioned by shocks given to the air by the *elastic tongues of wood* when they slip from the notch or tooth of the wheel which inflects them. The vibration of the tongues themselves, and of other parts of the machine, contribute a little to the sound, especially to its distinctive character, but is by no means of primary importance.

Grating of a saw.

26. A common HAND-SAW produces a grating noise: 1st, because the little film or body of air between

ed against the tooth struck; and
lly, because the metal which com-
es the tooth is, by the act of sawing,
own into a state of vibration. The
nd is *harsh and disagreeable*, because
the grain of the wood does not
sent equal resistance at every part;
the motion of the arm in the act
sawing is unequal; and (3) the
th are neither uniformly of one size,
perfectly equidistant; so that, tak-
all the circumstances together, the
pulses given to the air are without
er measure, time, or rhythm.

27. The RATTLING of CARTS over
nes is a phenomenon of pre- Rattling of carts.
ely analogous character. The
is forced by the wheels against the
nes struck; and the stones being

28. The report of a STONE projected from a VOLCANO seems to those at a *distance*, like the roar of artillery, but to those *close* to the mountain it seems to be no louder than a deep sigh. Because when a person stands at the foot of a long sounding column, like that produced by the upward rush of a stone hurled from a volcano, the noise reaches his ear in *detail;* whereas, at a distance, the sound-rays of the whole column fall upon his ear with a succession sufficiently rapid to produce the impression of a single sound.

Stone from a volcano.

All the sound-rays which arrive within the space of *one-twelfth* of a second combine to produce a single impression.

SEC. III. SOUND PRODUCED BY SHOCKS GIVEN TO THE AIR BY AIR.

29. Many of the loudest sounds with which we are familiar are occasioned by the percussion of air against the air. For instance: the report of a

gun and the pealing of loud thunder, the detonation of an exploding mine and of fulminating powder, the blast of a trumpet and the piercing shrillness of an octave-flute.

30. The tremendous noise of exploding GUNPOWDER is occasioned in the following manner: certain highly elastic gases, engendered by the inflammation of the powder, are suddenly developed, chase the air which they encounter with considerable violence and greatly *condense* it. This condensed air, being driven back against adjacent strata, condenses them in turn, and these latter, repelled against more remote portions, produce the same effect. In the meantime the new-formed *gases* either condense or diffuse themselves, leaving a vast void. The condensed air rapidly *dilates* in order to occupy this void; and currents flowing in from opposite sides, clash together with enormous violence, producing a new

Explosion of gun-powder.

series of condensations at the very moment of their rarefaction. This latter is the cause of the peculiar *roll* which characterises an explosion of gunpowder. The *original sound* being due to the condensation and dilation of air, as the gases develop or condense, and the *rolling* to the collision of opposite portions of air as they rush forward to occupy the void from which they had been dislodged.

Gunpowder is made of nitre, carbon, and sulphur. Immediately it is inflamed, these three solids form into different combinations, so as to make *seven gases* and *three or four new solids.*

The action is as follows: the oxygen of the NITRE makes *three* combinations:

1. By far the largest part, by a re-action of the carbon, forms CARBONIC ACID and NITROGEN;
2. A small portion, by the re-action of the sulphur, forms *sulphurous acid;* and
3. A small portion, by the re-action of the hydrogen contained in the carbon, forms the *vapour of water.*

The SULPHUR also makes three combinations, besides that of sulphurous acid mentioned above.

A part reacts on the carbon to form the *sul-*

phure of carbon; and the rest on the potass of the nitre to form two new solids, viz. *sulphate of potass* and *sulphure of potassium.*

The residue of the three ingredients forms into *carbonate of ammonia, carburetted hydrogen,* and *carbonate of potass.*

N. B. Every cubic inch of powder after inflammation displaces 4000 cubic inches of atmospheric air.

31. The explanation given above of the noise produced by exploding gunpowder is applicable to all the different sorts of DETONATING substances. In the oxides of gold, silver, and mercury, it is the *oxygen* which passes from the solid to the gaseous state. In the nitrates it is the *nitric acid* which is decomposed, and reproduces its elements in a gaseous form. Whereas in the powders whose base is a muriate, it is the *chlorine* which vaporises, and the oxygen that is disengaged.

Detonating powders.

32. The noise of CRACKERS, lucifer-matches, and sky-rockets, is likewise due to the sudden gasification of their ingredients, which ex-

Crackers.

[redacted]

pand to a considerable volume, and give the air a proportionate shock.

CRACKERS are made of fulminating silver, which may be very easily obtained by dissolving a silver sixpence in an ounce and a half of nitric acid, and then heating the mixture with two ounces of alcohol. Great care should be employed in making these toys, as frequent accidents occur in the manufacture of all fulminates.

Common LUCIFER-matches are made of chlorate of potass two parts, phosphorus four, gum-arabic seven, gelatine two, and a little indigo or minium. Lucifer-matches which do not *detonate* are made of refined saltpetre ten parts, phosphorus four, gelatine six, minium or ochre three, and smalt two.

CONGREVE ROCKETS are made of saltpetre and bitumen, to which is added a little sulphur and a little grease.

Common sky-rockets are made of nitre, charcoal, and sulphur, confined in a cylindrical case of paper tied to a stick.

Thunder.

33. The noise of THUNDER is occasioned in a manner somewhat similar to that of ignited gunpowder; the phenomenon is, however, a little more complex, and requires an explanation somewhat in detail.

A PEAL OF THUNDER consists of three parts:

(1.) The *primitive* or fundamental sound;

(2.) The *secondary* sound, which constitutes the roll or rattle; and

(3.) The *resonance* or auxiliary sound.

34. The *primitive* sound is occasioned by the sudden *precipitation of air* into the furrow made by the lightning-flash. This sound is somewhat augmented and modified by the various noises produced by the chemical changes* which the flash calls into action in the molecules of air along its immediate path.

The peal.

* Among these changes may be mentioned the reversion of the polarity of the molecules of air; the formation of nitric acid, by placing in *combination* the two chief gases of the atmosphere; the instantaneous condensation and alternate rarefaction of the air in immediate advance of the flash; the disturbance caused by the heat of the fluid through a bad conductor; and many others, which will be fully explained in the Second Series of these scientific tracts.

[redacted]

35. The *secondary* sound or *roll* of the thunder is due to the *precipitation of adjacent clouds* into the void created by the fall of rain which follows the flash. Let us explain: The clouds are water in an *aëriform* state. The lightning converts a large mass of this vapour into a *liquid* state, reducing its volume 1728 times*, and leaving of course an enormous void. The superincumbent clouds precipitate themselves into this void, and a general movement takes place in all the adjacent parts in order to restore equilibrium. The noise made by these various collisions sometimes reaches the ear simultaneously with the primitive sound, and the two produce one tremendous crash. Sometimes, however, the clouds are so far off that the noise proceeding from their concussions does not reach the earth till more than the

The roll of thunder.

* The ratio between water in a *liquid* state and water in a *gaseous* state is as 1 to 1728.

twelfth part of a second after the primitive sound, and in that case a second loud noise is heard constituting a double peal, roll, rattle, or distinct roar.

36. The *repetition* of the roar is due to the repetition of the phenomenon just referred to. As soon as the *first* void has been filled up by the superincumbent clouds new voids must be left in the parts vacated. The clouds, therefore, *dilate* in order to fill these voids, become supersaturated, and render more rain, leaving fresh voids of less extent to be filled up in a similar manner. Every fresh void occasions a renewal of the noise, each succeeding roar being, however, more feeble than the former.

Sustained thunder.

37. The *third* part of the phenomenon of thunder is from *resonance*. All these several sounds are frequently increased and modified by echo, either from the thick clouds, or from some terrestrial objects,

Effect of echo on thunder.

as forests, mountains, extensive buildings, the soil towards which the sound is directed, or the surging waves of the troubled sea.

SEC. IV. SOUND PRODUCED BY A COMBINATION OF SHOCKS OF DIFFERENT CHARACTERS.

38. Comparatively few sounds are really simple, and, therefore, it is much more easy to make a selection to illustrate the preceding sections, than to fix upon a compassable number of *compound* sounds, which may serve as types or examples for the solution of others. We shall, however, select some of the most familiar, and leave the ingenious reader to apply the matter of the chapter, as his fancy may dictate, to any other of the ten thousand times ten thousand noises which meet his ear in town or country, in the air, on land, or on the pathless deep.

§ 1. *Compound Sounds without Resonance.*

39. The CRACK of a WHIP is due to three concomitant causes. 1st, to the shock given to the air by the *lash;* 2ndly, to the *inequalities* in the surface of the braided thong; and, 3rdly, to *the collision of the air* when it returns to the place from which it has been dislodged.

Crack of a whip.

When a jerk is given to a whip, the thong first coils, then unfolds suddenly and coils again, displacing and condensing all the air which it encounters. The air, condensed by the lash and thong, rapidly dilates to reoccupy the voids, and the noise produced is proportionate to the rapidity with which the thong moves from one place to another.

40. The EXPLOSION of a hot CHESNUT is a compound noise arising partly from the same cause as the detonation of *gunpowder*, and

Explosion of hot chesnuts.

partly from a cause similar to th which produces the *crash of falli timber*. It is occasioned, 1st, by t *gasification of the air* contained in t fruit; and, 2ndly, by the sudden ru ture of the rind and of other parts the chesnut.

41. When the rind has been pr viously *slit*, a roasting chesn makes no explosion, because t hot air can then issue freely and gr dually through the fissure.

Slit chesnuts.

42. The CRACKLING of burning SA is due to the following caus 1st, the *water* interposed very minute quantities between crystalline lamelles* of the salt is duced suddenly into *vapour*, and duces a noise in the same wa ignited gunpowder; 2ndly, the ductibility of salt being extr

Crepitation of salt.

* Lamelles (*two syllables*) are exceedin scales or plates. A grain of salt contains n little cells, the walls of which are its c lamelles.

feeble, the heat of the fire produces a *crowd of little ruptures* in each crystal.

43. The REPORT of a STONE when it flies from the fire is capable of a similar explanation. (1.) The heat of the fire sets at liberty the *water of crystallisation* contained in the stone; and (2.), as the texture of the stone is extremely compact, it affords no issue to the heated air and vapour; which, consequently, burst the stone into fragments, and project the different parts with great violence into the room. The accumulated force of these several shocks gives rise to a sound of considerable intensity.

Report of heated stones.

§ 2. *Compound Sounds with Resonance.*

44. To this category belong a large number of wind instruments, to which a separate chapter (*Chap. VI. Part II.*) has been assigned; the present section, therefore, will be illustrated by various sounds not strictly of a musical character.

Roar of a furnace.

45. The ROAR of a FURNACE is occasioned: (1.) by the *shock of air against air;* and (2.), by the *resonance of the furnace.*

When the furnace door is *closed*, the external air forces its way into the stove through the *crevices around;* but can enter only at recurring periods or by *puffs*, because it is shut out every time a fresh portion has gained admission, till this newly-admitted current has become rarefied by the heat of the fire. The cold air which forces its way through the crevices of the furnace door, *condenses* the hot air for an instant, and the condensed mass is then *dilated* by the heat of the fire. These condensations and dilations, which take place with rapid succession in the enclosure of the furnace, give birth to the roar so familiar to all.

Character of the furnace roar.

46. The peculiar *pitch* of the roar depends on the construction of the furnace itself. A *small* aperture gives a higher note

than a larger one, because small vibrations are more quickly made than those of greater amplitude.

"Pitch" is a musical term, and here refers to the high or low tone of the furnace roar.

47. When the furnace door is *open*, the noise is considerably lessened, and sometimes scarcely audible; both because the air no longer enters by puffs but in a continuous stream, and also because the rarefactions and condensations are much more *gradual*.

Roar less with the furnace door open.

48. The SINGING of a TEA-KETTLE has been observed and sometimes anxiously waited-for by every householder. A phenomenon so familiar, and of a character so thoroughly domestic, cannot be without interest.

Singing tea-kettle.

As soon as water begins to simmer, steam is formed at the bottom of the vessel which contains it, and, in virtue

of its lightness, rises through the liquid. Some of these vesicles* of steam find their way into the kettle-spout, and, bursting at the surface of the water, discharge the vapour they contain with a kind of belch. The air in the spout is *condensed* by these shocks, and dilates again in obedience to its elasticity, as the air contained in a flute dilates after it has been condensed by the shock of the breath. So that the singing of a kettle is produced in a manner precisely analogous to the notes of a flute or trumpet.

The chant thus created is reinforced by resonance, and is somewhat modified by the vibrations of the metal itself.

Water contained in vessels without a spout *sings* before it boils, though not so loudly. In such cases the bursting vesicles of steam shock the air and walls of the vessel between the *water*

* Vesicles are little bubbles or bladders, as those of vapour, &c.

and the lid. The same doubtlessly occurs in the common tea-kettle, but then the more powerful chant of the spout buries the feebler sound, in the same manner as the note which issues from the *bottom* of a flageolet incorporates the harmonic formed at what is termed the "mouth"* of the instrument.

49. BOILING water NEVER SINGS: 1st, because the hot steam *expels the air* from the kettle-spout, or so *rarefies* it that it is no longer capable of conducting sound; and, 2dly, because the steam no longer *shocks* the air with puffs or jerks, but issues forth in a continuous current.

Boiling water never sings.

50. When boiling water *cools*, the singing begins afresh, because ascending vesicles of steam again burst in the spout, where a

Chant of cooling water.

* The mouth of a flageolet is the little hole near the top, the lower edge of which is bevelled and inclined inwards.

[redacted]

column of air is re-established of sufficient density to propagate the impulsions thus communicated.

Hum of humming-tops.

51. The MURMUR of a HUMMING-TOP is another phenomenon of familiar occurrence which deserves a passing notice. The humming-top is furnished with a small aperture sometimes bounded by a sharp bevelled edge. One side of this edge being pushed, by the rotation of the top, against the external air, *cuts it*, and *catches up* the part cut off into the hollow of the toy. As the top was previously *full of air*, this extra quantity compresses the portion nearest the aperture; the part condensed condenses other portions more remote, and then dilates, establishing both within and without the toy a series of sound-waves, which are augmented by resonance and modified by the vibrations of the top itself.

52. It cannot have escaped observation, that the cry of a top differs con-

iderably in pitch between its first and ast gyrations. There is first a hriek, which relapses into a teady murmur, and this murnur gradually ceases as the top begins o stagger prior to its fall.

The pitch of a humming-top.

The first gyrations produce the oudest shriek, because the top then akes a wider range and disturbs more ,ir. The steady hum of what is called he top's "sleep" arises from the great apidity and steadiness of its rotatory novement at this particular period, vhen the vibrations follow so quickly ıpon each other, that they produce he impression of one monotonous un-)roken sound. As the top staggers, ts motion becomes more *slow*, and the ıperture can no longer cut the air with he same precision. At this time, there-'ore, the sound becomes more and more 'eeble, till the top ultimately falls.

53. The MOANING and whistling of WIND just prior to rain is oc-;asioned by the *descent of the*

Moaning & whistling of wind.

heavy masses of cloud to the lower regions of the atmosphere; in consequence of which the air is compressed and set in motion. Unable to find a vent through the thick clouds, it forces its way through every accessible aperture; especially through keyholes, and the crevices of doors or windows, where it meets from the tranquil and rarefied air of the room but very little resistance. For a similar reason it makes its way through forests and belts of trees, alleys, and other confined places, where the air circulates slowly, and cannot readily accommodate itself to a sudden change of temperature.

The nearer the storm, and the more the clouds are surcharged with rain, the louder is the howling or whistling of the wind.

Report of a gun.

54. The REPORT of a GUN or cannon is occasioned by the *expulsion* and *re-entry* of air into the piece after the explosion of the powder. The

powder being inflamed, develops a considerable quantity of gas, formed by the decomposition and re-action of the different ingredients of which it is compounded (*No.* 30. *note*). These gases rushing from the interior of the piece, propel the projectile which covers the powder with enormous force, and chase from the muzzle the mass of air A vacuum is thus created in the interior of the gun or cannon; and the external air, entering with precipitation to restore equilibrium, gives *to the metal walls a shock* which makes them vibrate. The tremendous noise which accompanies the discharge of fire-arms is the combined effect of these several disturbances.

55. When gunpowder BURSTS a GUN the report is far greater than ordinary, because every fragment of the broken barrel gives the air a separate shock, but all the shocks combined produce only *one impression* on the ear.

Report of a bursting gun.

The same explanation applies to the explosion of a steam-boiler.

56. There are many sounds of familiar occurrence analogous to the report of a gun. For example: when a person draws off briskly the LID of a BODKIN-SHEATH or pen-and-pencil case, a noise is produced like that of a pop-gun. For, as the air in the sheath is *more rarefied* than the external air, immediately the lid is removed the rarefied air *rushes out* and external air *rushes in*. The encounter produces a shock, and the noise of the shock is augmented by vibrations in the material itself of which the case is composed.

Report of a bodkin or pen-sheath.

57. Another analogous noise is produced by the following pneumatic experiment: a small glass cylinder, having a piece of bladder nicely adjusted over the upper orifice, is placed on the plate of an air-pump. As the air contained in the glass is exhausted, the bladder is forced inwards

Receiver and bladder.

by the weight of the in ..uent air, till at length, being no longer able to support the pressure, it bursts with an explosion, like that of a pistol. This noise is occasioned by the rush of the external air into the "receiver" to fill the void created there by the action of the pump. The violence of the entry shocks the walls of the glass and the plate of the machine; the vibrations are communicated to the table; and the noise is further increased by the echo of the walls, floor, and ceiling of the room.

58. The report of a POP-GUN is produced in a similar manner. Sometimes *two* balls are employed and *compress* the air confined between them. As soon as one of the)alls is discharged this condensed air lilates suddenly, and shocks the adıcent air.

Pop-guns.

Sometimes only *one* ball is used, and ·en the noise is occasioned chiefly by the sh of air into the pop-gun to replace

that which has been expelled by the ball. In both cases the noise is increased by the column of air confined in the tube, by resonance, and by vibrations established in the walls of the gun.

Sometimes the ball is discharged into the hand. The report is then somewhat augmented, not so much from resonance, as because the hand renders the air which receives the discharge less *fugacious*, and compels it to abide the full effect of the shock.

Report of a cork.

59. The noise produced by DRAWING a CORK briskly from a bottle is occasioned by the rapid escape of rarefied air confined in the bottle, and by the no less rapid entry of external air to fill up the void. The shock of the encounter receives accession from the vibrations of the liquid and of the bottle, as well as from resonance in the parts not occupied by the contents.

Cork of a champagne bottle.

60. The noise proceeding from a bottle of CHAMPAGNE, soda-water, or ginger-beer, is further in-

creased by the violence with which the cork is expelled by the carbonic acid, and by the effervescence of the liquids.

61. When a GAS-BURNER surrounded by a globe chimney is LIGHTED from the top of the glass a report of considerable force is made: 1st, because the air in the globe is rarefied by the flame which sometimes plays for a moment on the *top of the glass*, before it descends upon the beak; and, 2ndly, because the vapour of water formed by combustion is rapidly condensed. By reason of these two actions a partial vacuum is formed in the glass, and immediately the flame descends upon the "burner," air rushes into the globe to restore equilibrium. The noise thus created is augmented by resonance, and by the "ring" of the glass itself. Report of lighted gas.

It is not essential for the chimney to be a *globe*, but such a form is very favourable to a loud report.

CHAPTER II.

QUALITIES OF SOUND.

62. SOUNDS differ from each other in three essential particulars:

I. In *pitch*, that is in gravity or acuteness;

II. In *loudness* or intensity;

III. In *timbre* or quality of tone.

SEC. I. PITCH.

63. The *pitch* of a sound always depends on the number of vibrations

communicated to the air in a given time. Rapid vibrations produce sharp shrill sounds; slower vibrations those which are more grave.

The low C of a piano-forte gives a deep bass note, the highest C an acute treble one. Not that one of these notes is touched more energetically than the other, but that the string of the former *vibrates more slowly* than the latter. Thus the lowest C of a six-octave piano makes only 64 vibrations, while the highest C makes 2048.

Low and high C.

64. A STRING is made to vibrate more slowly:

I. By augmenting its length;

II. By augmenting its weight;

III. By decreasing its tension.

Strings.

65. In WIND-INSTRUMENTS the lower notes are obtained principally:

I. By lengthening the tube; and

II. By diminishing the force of the blast.

Pipes.

By increasing the *calibre* the tone of a tube is flattened a little; and metal organ-pipes are flattened by *pressing in* the "ears," so as to diminish the orifice called the mouth.

Organ. 66. In CHURCH-ORGANS the treble pipes decrease in size as they represent the higher notes; and are both larger and longer as the note required from them is more grave. The lowest C pipe of an organ is often 32 feet long, while the highest C pipe is not more than an inch-and-a-half.

Trombone. 67. In the TROMBONE, a sliding tube is drawn out to a greater or less extent as the performer wishes to increase or diminish the length of his instrument, and to produce thereby lower or higher notes.

French-horn. 68. In the FRENCH-HORN the same purpose is effected by sliding the hand up the sides of the "bell" or pavilion. But in these, and indeed in almost all wind instruments played by the breath, greater variety is produced by the lips of the performer

than by altering the length of
employed.

Keyed-instruments.

69. In KEYED-INSTRUMENTS, such as the flute, clarinet, hautboy, bassoon, and so on, the virtual lengthening and shortening of the tube are by means of the keys or finger-holes. As the performer uncovers the holes, he shortens the distance between the embouchure or mouth-piece and the orifice which determines the length of the vibrating column of air contained in the tube; effecting by this means what the organ-builder aims at by varying the size of his organ-pipes, the player on the trombone by sliding up and down the moveable tube, and the fabled Pan by joining together reeds of unequal length.

SEC. II. LOUDNESS OR INTENSITY OF SOUNDS.

70. The LOUDNESS or intensity of sounds is proportionate to—

I. The force of the shock which the air receives;

II. The density of the medium through which the sound-waves pass;

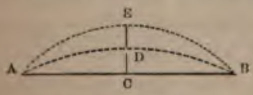
III. The uniformity of that medium;

IV. The absence of obstacles to interrupt the progress of the sound-waves; and

V. The proximity of the auditor to the original source of the sound.

§ 1. *The Loudness or Intensity of Sounds is proportionate to the Force of the Shock which the Air receives.*

71. That which gives the air the *greatest shock* produces the *loudest sound:* Thus, while the string A B swings as far as E it will produce a louder sound than when it vibrates no further than D; because the greater shock produces in the air a greater degree of compression, and sound-waves of a *more* decided character.



72. The explosion of *gunpowder* is ccompanied with a louder report than the cracking of a hesnut, because the enormous olume of gas generated by ignited unpowder gives a shock to the atmophere of far greater violence than the etty quantity of heated air which ursts from the rind of a roasting hesnut.

Gunpowder and roasted chesnuts.

The analogous ripple on the smooth urface of a lake would be far more leeply furrowed by the violent shock of a mill-stone, than if a small pebble vere dropped gently into the water.

73. Hard ELASTIC bodies produce generally the LOUDEST sounds, because they more readily transmit from molecule to molecule the impulsion given to any individual part, and consequently their agitation is greater than that of bodies possessing less elasticity.

Elastic bodies most sonorous.

74. For similar reasons, the sound of sonorous bodies is proportionate to

Sounds proportioned to the force of the blow.

the FORCE of the BLOW with which they are struck. Thus a church-bell struck with a huge sledge-hammer would render a much louder sound than if it received a mere fillip from the fore-finger.

§ 2. *The Loudness of Sounds is proportioned to the Density of the Medium through which the Sound-waves pass.*

Alarum of an air-pump.

75. The truth of this proposition is capable of a very simple, but no less decisive demonstration: let a *bell* be placed under the receiver of an AIR-PUMP. In exact proportion as the air is removed, the sound of the bell becomes less audible, and if a *perfect vacuum* could be established no sound whatsoever would be produced. If now a little air be re-admitted into the "receiver," a faint tinkling will be heard, and the sound will increase in loudness in exact proportion as the quantity of air increases. A small apparatus, called an *alarum*, is arranged

for this experiment. The
ı placed on a soft cushion of
cotton to prevent the conduc-
ound through the pump-plate,
ugh other parts of the ma-
ıd the bell is made to ring by
a governing rod, which passes
the top of the receiver.
ı the air in the higher regions
mosphere is extremely Mountains
ounds become less and quiet.
ble as we ascend in height.
ıses besides the rarefied state
ir contribute to this pheno-
specially the *isolated* character
ain-summits, where there is
o produce *resonance*, and no-
prevent the air from *flinching*
g away from the shock which
iven to it.

Saussure*, the celebrated

Benedict de Saussure was born at Ge-
itzerland, in 1740, and died in 1799.
ted naturalist crossed the Alps *fourteen*
r to make researches among the glaciers.
tions are published in a work entitled
s *les Alpes*.

De Saussure on Mt. Blanc. naturalist, affirms that the report of a *pistol* on the summit of Mont Blanc makes less noise than a common *cracker* discharged on the plain.

The *snow* on Mont Blanc would contribute to this effect.

Aëronauts. 78. Persons suspended in a BALLOON much elevated find it needful to speak with considerable exertion in order to render their words audible.

Ascent of G. Lussac. On one occasion, when Gay Lussac* had ascended to the unusual height of 23,000 feet above the level of the sea, he found that he could scarcely hear the sound of his own voice.

When a person has ascended very rapidly

* Gay Lussac was born at St. Leonard in France, A. D. 1778, and died in 1849. This celebrated chemist is reckoned one of the most distinguished philosophers of the 19th century. He has left a large number of works of incontestible superiority and of European reputation.

a stratum of air extremely rarefied, as Lussac did on the 6th of September, 1804, air contained in the *middle chamber of the* has not time to put itself in equilibrium the constantly decreasing density of the osphere; the drum is, consequently, stretched vard with such intensity, that its vibrations extremely feeble.

liss Martineau tells us, that she *lost her ness* during the time she was on the top of great pyramid. When deafness is due to a *great laxity of the tympanum*, as in the case rred to, the increase of tension, which would painful and prejudicial to others, would act t serviceably.

9. So imperfectly does rarefied air ismit the impulses of sound, that noise produced by the art of man propagate itself to the limits of atmosphere; and no noise whatver proceeding from celestial bodies ever reach to our earth.

0. Though air, when rarefied, is a conductor of sound, *dense* air is ery *good* one. Thus, when sons descend to a considerdepth in a DIVING-BELL, slightest WHISPER is audible, and if

Sounds intense in a diving-bell.

one were to speak in his ordinary tone, the noise would be painfully intense: 1st, because the upward pressure of the water greatly *compresses* the air of a diving-bell; in consequence of which, its density is so great that a very slight movement suffices to produce upon the air audible vibrations; 2ndly, because the original sound is greatly augmented by resonance from the sides of the machine; and, 3rdly, because the air, being unable to escape, is compelled to abide the full shock of the voice.

In the preceding case the descent is supposed to be deliberate and not sudden. Whenever a very rapid descent is made, sounds are not audible till the air in the *middle chamber of the ear* has put itself in equilibrium with that contained in the diving-bell; because the more dense air will press against the tympanum, and so increase its tension that it will be able to make but very feeble vibrations.

81. Sounds are in general unusually loud in VALLEYS where the air is dense, and where the surround-

Valleys *noisy.*

ing hills both echo them, and swell them by resonance. The air of valleys being also somewhat confined by the rising ground on each side is less able to slip away, and is consequently more condensed by a shock than air which is more fugacious.

The last idea I believe to be the most important of all the causes mentioned. Valleys act in the same way as *speaking-trumpets*, and *tubes of communication* (*See Chap.* VII. *Sec.* I.)

82. As *cold* condenses the air, sounds are heard more distinctly during a clear FROSTY day than in the hot noons of summer.

Sounds louder in a frost.

83. For the same reason, they are more audible in the FROZEN REGIONS than in climates of a higher temperature.

Frozen

84. Captain Ross* tells us, that when he was wintering in the polar seas, he could hear the

Capt. Ross.

* Captain Ross and Sir Edward Parry have rendered their names illustrious by their memorable

voices of his men in conversation at the distance of a *mile and a half*. And Lieutenant Foster on one occasion, during the third Polar expedition of Sir Edward Parry, held a conversation with a man on the opposite shore of Port Bowen, the distance between the speakers being a *mile and a quarter*.

Lieut. Foster.

85. Who has not observed that BELLS, CLOCKS, GUNS, and various other sounds, are LOUDER at NIGHT than by day? To the sleepless this intensity of sound is not

Sounds louder by night.

attempts to discover a north-west passage from England to China. The first attempt of the sort was made in the reign of Queen Elizabeth, by Sir Hugh Willoughby.

Captain Ross and Lieutenant (afterwards Sir Edward) Parry made their first voyage in the same vessel, in 1818. Parry made four subsequent voyages in 1819, 1821, 1824, and 1827. Captain Ross did not return from his second voyage till 1833. He had been absent for *four years*; and all hope of his return had been nearly abandoned.

Both these navigators have published very interesting narratives of their adventures in the North seas.

unfrequently the cause of distress and alarm. Without doubt, the stillness of night, when birds, beasts, and insects are hushed in sleep, when the hum of moving multitudes and the myriad noises proceeding from their several occupations are suspended, when the ear is not fatigued by incessant shocks, nor the mind intent upon business, an ordinary sound is isolated and stands out in strong relief; yet that the *condensation of the air* which ensues at sunset, bears an important role in the phenomenon will appear from this, — the same observation has been made in *tropical countries*, where the animals sleep during the hot day, and prowl, roaring for their prey, at night.

86. When the celebrated Baron Humboldt* was in South America, his attention was particularly directed to this phenome- Humboldt and the Orinoco.

* Baron C. G. de Humboldt, chamberlain and privy councillor to the King of Prussia, was born at Pots-

non. He assures us that the noise of the great cataract of the Orinoco * was at least *three times* louder by night than at noon-day. In the spot where he was staying he could never hear the roar of the falling waters till after sunset. This could not be owing to a cessation of noises at night-fall, or to the greater susceptibility of his ear, rested from fatigue, inasmuch as the humming of insects was much greater, and the rustling of leaves incessant after the setting in of the evening breeze.

§ 3. *The Loudness or Intensity of Sound is proportioned to the Uniformity of the Medium through which it passes.*

87. Some reasons why sounds are

dam, in Saxony, A. D. 1767, and died 1835. He was one of the most distinguished philosophers of the age; and his work called *Cosmos*, translated into nearly all the languages of Europe, forms almost an era in natural philosophy.

* The Orinoco is a large river of Caraccas, which issues from the small lake Ipava, in Guiana, and, after a singularly circuitous course, enters the Atlantic by an extended delta of mouths. Its cataract *is one of* the largest in the world.

more audible by night than by day, in winter than in summer, in the polar regions than in the torrid zone, have been already alluded to, but the phenomenon is due in part to another circumstance. When the warm sun has heated the surface of the soil, an upward current of hot air and a downward current of cold air are instantly established. These two currents destroy the *uniformity of the atmosphere*, which is still further interrupted by evaporation, shadows, and interfering sounds. When a sound-ray gets entangled in a medium like this, it is divided into two or more portions, the part in the denser medium being borne onward with more rapidity than that which is in the rarer; the contour of the waves is also disturbed, one part being urged *downwards* by the descending column of air, and the other part buoyed *upwards* by the rising current. Instead, therefore, of striking the ear with their entire force, the

sound-rays are broken up into fractions, and reach the ear in detail.

Church bells heard at intervals.

88. A person walking about a city often HEARS a church PEAL distinctly in one street, LOSES the sound in another, and again recovers it in full force immediately he enters a third. Whenever buildings intervene between the sonorous body and the listener, the sound is always diminished, and sometimes completely buried, partly owing to what is termed the *acoustic shadow*, and partly because sound cannot readily pass from one medium to another.

Cellars bury sound.

89. A main reason why the sound of VOICES in a CELLAR rarely penetrates into the rooms immediately above is because the space between the vault and the ground-floor is filled with sand or rubble; in consequence of which, the rays of sound which enter this debris are so wasted and frittered by the heterogeneous mass, that no sensible part emerges

through the floor of the incumbent room.

90. It is very different with the other parts of a house. Every noise in one chamber spreads into the rooms above, below, and on each side. We can hear the prate of feet as a person steps along the floor of an adjoining apartment. We can hear the murmur of voices in conversation, a burst of laughter, or the crying of children. We can hear the young pupil practising some tedious music-lesson or endeavouring to execute some popular song.

Sounds propagated from room to room.

91. This annoyance, in some cases very serious, may be wholly obviated by filling with tan, sawdust, shavings, cut straw, tow, or any similar substance, the space between the two surfaces of the partition walls, and that between the ceiling of one room and the floor of the other. One part of the sound-rays would then be reflected from the surface of the

Hint for partition walls.

walls without penetrating further, and the rest would be so refracted and divided by the several obstacles it would have to encounter, that no sensible part would be transmitted into the adjoining chambers.

Hollow bricks.

92. HOLLOW BRICKS were proved at the Great Exhibition to be *non-conductors of sound*. This is because the hollow part is filled with rarefied air, and every sound which finds its way into such a mass is effectually buried there.

Flock paper.

93. Brown paper, upon which flock or sawdust has been gummed or pasted, placed between the battening of partition-walls, is also a pretty efficacious and very economical means of arresting sound.

Cheap partition-walls.

94. It is truly surprising that no ingenious mechanic has yet contrived a substance for partition-walls, where cheapness and lightness are especially considered. Nothing, *for* example, could be easier than to

make panels with two sheets of common pasteboard, or tarpauling separated from each other by wooden blocks. Sawdust should be thickly strewed over the inner surfaces, and the intervening space be well filled with coarse tow or cut straw. A wooden "upright," the thickness of the blocks, would hold the panels in their place, especially if the edges were made to lap over the supporters. Such a partition wall would be a real boon in hotels, &c., where chambers are often separated by half-inch wood or by simple canvas.

95. Wool, hair, tow, shavings, cut straw, tan, sawdust, and so on, are *bad conductors* of sound, because they shut up a large quantity of air between their minute and detached parts; so that they cannot readily transmit an impulse; and when a sound becomes entangled in a mass of this sort, it can no longer preserve its regular outline.

Wool, straw, &c., bad conductors.

96. CARPETS and fresh-fallen SNOW deaden sound, because the echo which would otherwise combine with the direct sound and swell it, is smothered amidst the fibres of the one and the crystals of the other.

Snow, carpets, &c., smother sounds.

97. The British and American troops, on one occasion during the unfortunate war between these two nations, happened to be encamped on the opposite sides of the same river. The outposts were so near to each other, that a drummer was observed by the British troops on the American side moving his arms to the beat of his drum, but yet no sound whatsoever was perceptible. A heavy fall of snow had recently covered the ground, and the air was thick with the river mist.

American drummer.

§ 4. *The Loudness or Intensity of Sound depends on the Freedom of the Waves to spread themselves without Impediment or Interruption.*

98. Whatever interferes with the

onward march or regular outline of the waves diminishes the loudness of sound. Thus convective currents of hot and cold air passing each other, falling snow, hail, and rain, disturb the integrity of sound-waves and render sounds less intense. The same may be said of thaw, evaporation, fog, and even of the strong shadows of hills, houses, and clouds.

Hail, rain, snow, &c., enfeeble sound.

Shadows *enfeeble* sounds, because they change the temperature of the air in their vicinity.

99. On one occasion two of Captain Parry's crew, on the opposite sides of Port Bowen Harbour, were in conversation, when a *thaw* coming on, the voices were suddenly interrupted, and the speakers could no longer make themselves heard, even by the loudest shouts.

Thaw obstructs sound.

100. MOUNTAINS, houses, long walls, rocks, and all other obstacles which reflect sound, present a bar to its onward progress; and if at

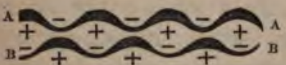
Hills, houses, &c.

any time a sound propagate itself beyond these hindrances, its force is very materially enfeebled.

Interfering sounds.

101. One of the most effectual, and certainly the most remarkable of all impediments to the propagation of sound is that of an INTERFERING sound. Suppose, for example, the undulations of one sound encounter those of another in such a manner that the elevations of the one series exactly coincide with the depressions of the other, then the two systems will be mutually effaced, and the two sounds effectually silenced.

Thus in the two series A A and B B,



if the *convexities* of the former measure exactly the *concavities* of the latter, and *vice versâ*, then the undulations of both series of waves will be entirely obliterated.

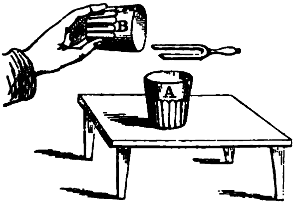
This interference may be expressed

$$\begin{array}{cccccc} + & - & + & - & + & - \\ - & + & - & + & - & + \\ \hline \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \end{array}$$

by the algebraic formula subjoined, in which the quantities of the under line being added to those of the upper, neutralise them.

102. This very remarkable effect is competent of a simple experimental illustration. Sound silencing sound.

Let A and B be two common beaker-glasses. Let the glass B be held exactly at *right angles* above the other.



Having caused a tuning-fork to vibrate, let it be held in the *middle of the angle* formed by the two beakers, and no sound whatsoever will be audible. Remove either of the two beakers, and the vibrations of the tuning-fork will be heard distinctly; restore the glass to its former position, and the sound will be again silenced. This process may be successfully repeated

ad libitum, so long as the fork continues vocal.

The reason is this: when the two beakers are at right angles to each other, the sounds proceeding out of them encounter each other in such a manner that one system of sonorous waves completely effaces the other.

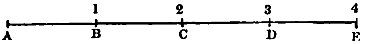
103. Another illustration of this very remarkable effect of interfering sounds is furnished thus: having excited a tuning-fork, place the tip of the handle on the extreme end of an iron bar, and it will communicate a sound till the rod is bent at *right angles*, when silence will ensue. If now the rod be still further bent, the sound will be reproduced, and its force will increase gradually, till the two parts of the bar are brought *parallel*, when the sound will be at its loudest.

Interfering rays of light also mutually destroy each other; and this furnishes perhaps the most satisfactory explanation of the *twinkling* of stars.

§ 5. *The Loudness or Intensity of Sound augments with the Proximity of an Auditor to its original source.*

104. In open space sound is propagated in all directions, like the light of a lamp or candle, but even the most powerful diminishes rapidly in loudness as it departs from its source, and within a moderate distance wholly dies away.

105. Conceive four men placed at equal distances from each other, as the letters B, C, D, E, along the



line A E. Let some one fire a pistol at A; then to C, who is *twice* as far off as B, the sound will be only *one-fourth* as loud; to D, who is *thrice* as far off, it will be but *one-ninth* as loud; and to E, who is *four times* the distance, it will be only *one-sixteenth*.

On the other hand, with whatever degree of intensity E may hear the

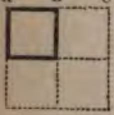
sound, D will hear it *four times* as loud, C *nine* times, and B *sixteen* times as loud as E. So that the loudness does not diminish inversely as the distance increases, but inversely to the *square* * of that distance.

Distance diminishes sound.

106. The cause of this rapid diminution of force is that the undulations of sound, like those of water made by a stone, are in *circles* round the centre of disturbance. Now, if one circle have a diameter *twice* as long as another, the circumference of the former will enclose a space *four-fold* as large as the latter.

This will appear evident from the following simple illustration:

A B C

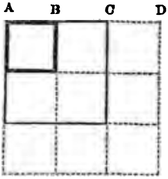


Divide A C into two equal parts in the point B; describe a square on A B, and another on A C.

It is evident that the larger

* The square of a number is the number multiplied into itself. Thus, the square of *two* is $2\times2=4$; the square of *three* is $3\times3=9$; and the square of *four* is $4\times4=16$, etc.

square described on A C contains *four* squares, each equal to that described on A B.



Again. If the line A D be divided into *three* equal parts, then the square described on the whole line A D will contain *nine* squares, each equal to the square described on A B.

Now, if we conceive a sound-wave condensed into the small square A B when it reaches the first listener B, and to be spread over the larger square on A C, when it reaches the *second* listener C, and again dilated so as to occupy the whole square described on A D, when it reaches the third listener D, it is evident that the density of the wave, or (if you will) the loudness of the sound is diminished *four-fold* at *twice*, and *nine-fold* at *thrice* the distance.

107. In a THEATRE, if those who

[redacted]

occupy the orchestra stalls be placed at a given distance from the actors, those in the middle of the pit *twice* as far off, and those in the back seats *thrice*, then the volume of the performers' voice will be diminished *four-fold* in passing from the orchestra to the pit, and *nine-fold* when it reaches the audience most distant from the stage.

Theatres.

This is not altogether true, except in the open air, in as much as those nearer the *walls* of the house have the compensating advantage of greater *resonance*.

SEC. III. TIMBRE OR CHARACTER OF TONE.

108. Every voice, every musical instrument, and indeed every thing capable of rendering a sound, has a specific character of tone, which the French call its *timbre*, and the Italians its *metal*.* Some are more sweet, others

* The expression *metallo di voce* is applicable, not only to human voices, but to all sonorous bodies.

more rich, some are more clear, others more mellow, some have a reedy quality, others a drone, and others again a "tinniness," a silvery clearness, or a harsh bray. Any ear the least practised can discriminate between the sounds of a flute and those of a hautboy or clarinet, between the tones of an organ and those of a pianoforte. The same note may be sounded, the pitch and intensity may be identical, the unison perfect, yet is there an indescribable something in the tone of each, by which it is characterised as distinctly as a tree by its leaf, a flower by its perfume, or a bird by its whistle.

It is by this "feature" of the voice we can distinguish one person from another, as well as by the contour of the face. By the same means we can, by the ear alone, identify persons of different sexes, ages, conditions, provinces, and even families. By the same individuality of tone, we can discern with

infallible certainty the various emotions of the soul. It is chiefly by the peculiarity of its tone, that the careful housewife tests the soundness of a vase she intends to purchase; that we can ascertain if a cask be empty, full, or only partially void; that the skilful physician will discern the healthy or disordered state of those parts of the body concealed from actual inspection. The sound of hail beating against the window or pavement is distinct from that of rain, the pattering of the eaves-drop from the report of a falling pebble, the cry of sterling money from that of counterfeit coin, the crash of breaking wood from that of breaking crockery, the uproar of the ocean from that of the hurricane and the storm. Without doubt, in some of these sounds there are other distinguishing features besides the mere quality of their individual tone, so are there other marks whereby the eye recognises different

persons besides the mere lineaments of the face. These auxiliary aids are like a second witness in a court of law; though the point at issue may be proved by *one*, it is nevertheless expedient that it receives confirmation from additional testimony.

109. The practical utility of this individuality of tone is of daily and hourly occurrence; but the *cause* of it is not fully understood. The different materials of which things are made, their diversified shapes, their elasticity or non-elasticity, their smoothness, fineness of texture, tenacity, and constitution, and the thousand indescribable varieties which modify them, produce some unknown effect on the symmetrical rarefactions and condensations of the sound-waves sufficient to characterise their tone, and give to each that peculiar trait, as difficult to define, yet as palpable to the senses,

Cause of timbre.

as the unknown something which enables the wearer to select his own hat from a crowd of others bearing the same shape, the same date, the same colour, and made perhaps by the same manufacturer.

CHAPTER III.

TRANSMISSION OF SOUND.

Sec. I.—By water.
Sec. II.—By solids.
§ 1.—The earth.
§ 2.—Animal substances.
Experiments by Chladni.

110. SOUND-WAVES are propagated best by those substances which most readily transmit an impulse from molecule to molecule. Thus *dense* air is a better vehicle than rarefied air, and this latter than gases of a less specific gravity. Water, on the other hand, in consequence of its superior density, conveys sounds, under favourable circumstances, both faster and with less loss than atmospheric air; and many solids still better than water.

Respecting the transmission of sound through atmospheric air, enough has been already said; the present section,

therefore, will be appropriated to the acoustic properties of water and of solids.

SEC. I. WATER A VEHICLE OF SOUND.

Sounds heard under water.

111. DIVERS can hear under water what is said on the banks of a river; and, reciprocally, two stones struck together at the bottom of a lake produce a sound which may be heard at its surface.

Exp. by Nollet.

Thus the Abbé Nollet*, having descended to various depths, assures us he could distinctly hear sounds made in the air, as those of the human voice, of a clock, horn, hammer, &c.; indeed every one must have noticed that when a fish lashes the water suddenly with its tail the noise is, in many cases, audible on the banks of a pond.

112. These instances (though suffi-

* The Abbé Nollet was an eminent natural philosopher of the last century. He was born at Pimbré, in France, and died in 1770, at the age of sixty-nine. He published a work on *Experimental Physics*, and another on *Electricity*.

cient to prove that water is c transmitting sound) appear neverthe-less under very unfavourable circum-stances; for as the density of water dif-fers very considerably from that of air, and as sound passes with difficulty and loss from one medium to another, it is impossible to hear in water sounds made in atmospheric air, or *vice versâ*, without great attenuation of force.

113. Other experimenters have at-tested the capacity of water to convey sounds without com-pelling the vibrations to change their medium. Thus Dr. Franklin*, having plunged his head under water, heard at *half a mile* distance two stones struck together beneath the surface.

Exp. by Franklin.

114. Professor Robinson† of Edin-

* Dr. Benjamin Franklin, of Boston, in North America, was one of the most eminent philosophers that ever lived. He proved lightning to be identical with *electricity*, was the inventor of *lightning-conductors*, and the author of several works. He died in 1790, at the age of eighty-five.

† Professor Robinson, born in Stirlingshire (Scot-

burgh, having plunged his head under water, heard at the distance of 1200 feet the sound of a bell rung in the same lake.

Exp. by Robinson.

115. Mr. W. Anderon caused three persons to dive under water about the depth of two feet, and in that situation they heard the rushing of a stream through a flood-gate twenty feet from the place where the experiment was made.

Exp. by Anderon.

116. Some noises are much more readily transmitted through water than others. Thus, the blow of a hammer on a sunk bell may be heard under water for *several miles*, and even the rattling of a chain-cable for 4000 or 5000 yards: whereas the fall of water through a sluice, and the paddles of a steam-boat of 100 horse-power, seem at the dis-

land), died in 1805, at the age of sixty-six years. He succeeded Dr. Black as professor of chemistry at Glasgow, and was afterwards chosen professor of natural philosophy at Edinburgh. His best-known work is entitled *Elements of Mechanical Philosophy*.

tance of fifty yards like the droning of a bee, and at double that distance are quite inaudible. As the noise of a chain-cable agitated in water makes itself heard to such an extraordinary distance, surely some practical use might be made of this important fact, in times of war, to apprise a fleet when the enemy is weighing anchor.

Exp. by Colladon and Sturm.

117. By far the most important experiments on this subject were made in 1827, by Messrs. Colladon and Sturm in the Lake of Geneva. As, however, we must refer to these experiments in the next Chapter, which treats of the Velocity of Sound, we shall now merely state three important facts: 1st, they heard the sound of a bell struck with a hammer three feet under water, quite across the lake, from Rolle to Thonon, a distance somewhat exceeding *nine miles;* 2ndly, they found that any obstacle intercepting the sonorous body rendered the loudest sound indistinct even

at the distance of a few yards; 3rdly, by plunging a bar of metal partly in water, they discovered this remarkable fact, that at a *few yards'* distance, the sound transmitted by the *air* was the louder; but when they moved further off, the sound transmitted by *water* had lost so little of its force, that it was by far the more intense; by again retiring to a still greater distance they entirely lost the sound in the air, although in the water it still continued distinctly audible, — an indisputable proof that sound is transmitted by water with far less diminution of force than when it spreads through atmospheric air.

Diffusion of sound in water.

118. It is probable, from these experiments, that sound-waves do not diffuse themselves in water upwards and downwards with the same facility as *horizontally* along the strata in which they originate; and that, therefore, sounds in water do not diminish in force according to the

square of the distance, as they do in air, (105.), but in *simple inverse proportion*, or nearly so.

119. Sounds are also carried along the *surface* of water with extraordinary facility. Thus a few years ago persons at Calais and Dover heard the cannonading at Waterloo; on another occasion they heard the noise of artillery proceeding from some troops in field exercise at Denderleeuw, about twenty-five miles from Brussels, the distance between the troops and those who observed the sound being at least 130 miles. The sound of cannon was heard at sea about the same distance when the British troops landed in Egypt. In the famous engagement of the Dutch in 1672, the report of the guns was heard booming over the ocean 200 miles from the scene of action. Sir Stamford Raffles* tells us of a

Examples.

* Sir Thomas Stamford Raffles was born at sea, 1781, and died 1826. He was some time lieutenant-governor of Sumatra, where he distinguished himself

still more extraordinary instance of the spread of sound over the surface of water: in the eruption of Tumbora, in Sumbawa, an island of the Pacific Ocean, A.D. 1815, the noise of the volcano might be heard anywhere round the island at the enormous distance of 850 miles.

In all these cases, without doubt, a gentle wind was moving in the direction in which the sounds were heard.

SEC. II. SOLID SUBSTANCES GOOD VEHICLES OF SOUND.

120. Many solid substances, especially those whose parts are consistent and compact, convey sounds with extraordinary facility, because they very readily transmit an impulsion from one particle to another.

by many philanthropic institutions. He wrote a *History of Java;* but his valuable papers on Sumatra, and all his property, amounting to 30,000*l.*, were lost by fire as he was returning from his residency to England in 1824.

121. If a BEAM of timber be scratched at one end with a PIN, a person who applies his ear to the other extremity will hear the sound distinctly, although another standing close by be unable to detect the slightest noise. The beam is a good conductor of sound, both because its particles are so close, so little fugacious, and so uniform, that the slightest impulse is communicated with facility from one to another; and also because it acts as an acoustic tube in preventing the *spread* of the sound-waves, which, being limited to the girth of the timber, propagate themselves only in one direction, and present themselves at the further extremity in a compact and concentrated form. Scratched beam.

122. It is by no means unusual to see a DEAF man take his seat beside a pianoforte, holding in his hand a CANE, one end of which he rests on the instrument, and the other applies to his ear. By this Deaf men hearing through a cane.

contrivance he is enabled to enjoy the music which would be otherwise inaudible to him. The action of the cane is precisely analogous to that of the beam explained in the preceding paragraph. As soon as the sound-rays reach the further extremity of the conducting rod, they communicate their vibrations to the teeth, shake the bones about the regions of the mouth and ears, communicate a similar motion to the nerve of hearing, and create a forcible impression of sound.

It is, however, evident that if a deaf man can hear by means of such an artifice, the *auditory* nerve must be in a pretty healthy state, and that his deafness proceeds from some disease or imperfection of the *tympanic* apparatus.

123. The following juvenile experiment is not unworthy of notice in this place. Having placed the palms of your hands over your ears, let some one pass a piece of TWINE round the back of your head and over

Poker and string.

the back of your hands; then let him tie a POKER to the two ends. If now you cause the poker to oscillate, so as to strike against the bar of a fire-grate, you will hear from every percussion a noise almost deafening, which to others will seem by no means unusually loud.

124. The preceding experiment may be somewhat varied in the following ways: Instead of a poker, let a WATCH be attached to the ends of the string, and the ticking will be much louder than ordinary. Next, remove the watch, and let some one, having tightly stretched the string, RUB it between his fingers or SCRATCH it with his nails, and the noise will resemble that of distant thunder, whereas the operator or a by-stander will hear little or nothing.

Watch and string.

The string scratched.

125. In all these cases the impulse given to one part of the string is readily communicated to every other portion; and as the diameter of

Explained.

the twine is very small, the sound-waves lose nothing of their force by diffusion or divergence. If the string be *relaxed*, the sound is no longer discernible, because then an impulse can no longer be communicated from one end of it to the other.

§ 1. *The Earth a good Vehicle of Sound.*

126. Smooth elastic bodies form favourable channels of sound: as, for example, the surface of ice, hard snow, water, and earth. BEASTS, whose ears are near the ground, hear the peculiar rumbling which precedes the outbreak of a VOLCANO before the air apprises men of it; consequently, the inhabitants of volcanic countries take warning of the approaching danger from the agitation and terror of cattle.

Acute hearing of cattle.

127. Several extraordinary instances of this power of the earth to convey

sounds are mentioned by travellers. Thus the stupendous cataract of the Missouri in North America first attracted the attention of Lewis at the distance of seven miles; and, according to Ellicot, the sound of the famous Niagara Falls are not unfrequently audible twenty miles off. The roarings of the Cotopaxi, a volcanic mountain of the kingdom of Quito, in South America, have been heard in New Granada, a distance exceeding 600 miles. Examples.

128. Savages often make a very sagacious use of this power of the earth to transmit sounds. They place their ear against the ground, and by this means discern the approach of persons, horses, and animals of chase, at a very considerable distance, long long before the babbling air "prates of their whereabouts." Savages listening at the ground.

129. The Arabs employ similar means to detect the arrival of a ship. When a vessel is expected, they will listen at day- Arabs listening for ships.

break with their ear on the water, and will hear the signal-gun above 100 miles from land.

130. A sentinel once on duty at Windsor was tried by a court martial for sleeping at his post. He pleaded that he had been awake up to the time his watch expired, and that the guard of relief was behind the appointed hour. He stated, by way of proof, that the church clock of St. Paul's cathedral, London, had *struck thirteen* instead of twelve. This upon investigation being found correct, saved his life. The soldier stated that he had placed his ear upon the ground, and had by this means heard, at the extraordinary distance of sixteen miles, the strokes of St. Paul's clock.

Windsor sentinel.

131. Probably the wonderful sagacity of DOGS in detecting the dangerous subsidence of a house (if indeed credit may be reposed in any of the numerous anecdotes of their extraordinary prescience in this respect),

Sagacity of dogs.

is not so much due to their eye or to their instinct, as to their *ears*, which, being near the earth, receive from it the alarm before the air has been able to report it.

§ 2. *Animal Substances transmit Sounds.*

132. That ANIMAL substances have the power of transmitting sounds may be inferred from the experiment of the *scratched string*, and from those analogous to it, mentioned in preceding paragraphs (123, 124.), in all which cases the sound had to permeate the hands and occiput of the head in order to reach the nerve of hearing. As a rule, however, animal substances are by no means good conductors of sound, yet cartilage is far better than the softer parts, and bone better still than cartilage.

133. By applying the ear to the left side of the chest, any one may hear the "beat of the heart," as it is called; and by applying it to a

Beat of the heart.

certain part of the back, the noise which accompanies respiration may be heard.

Hearing without ears.

134. Two persons who have stopped their ears can converse with each other if they hold a piece of *string or packthread* tightly stretched between their teeth; or if they hold between their teeth the two respective ends of a common *stick;* or if they only *press their teeth* against it. They may converse also by merely resting a stick against their *throat* or *chest.*

Exp. of Chladni.

135. Chladni *, whose labours in the science of acoustics have been so eminently ingenious and successful, mentions the following manner of conveying sounds through the BONES

* Ernest F. F. Chladni, natural philosopher, was born at Wittenburg, in Saxony, A. D. 1756, and died in 1827.

He is celebrated for his ingenious researches in the science of acoustics, and for the invention of two new musical instruments.

Chladni and Savart have done for acoustics what Hooke and Boyle did for the air-pump, Watt for the steam-engine, Linnæus for botany, and Cuvier for zoology.

of the HEAD, while the ears are stopped with wadding. You are to hold a stick by one extremity between your teeth, and to place the other end in a jug, glass-beaker, or basin. If now a person speak, directing his voice into the same vessel, the stick will convey the words to your organ of hearing, although your ears be "sealed up close as night."

Fishes hear.

136. There can be no doubt that FISHES have the power of hearing, although they have neither *external* nor even *middle* ears.* They exhibit every symptom of alarm at loud noises; generally desert rivers in which steam-boats ply; and at the sound of a gun start away in terror. It is universally known that all anglers preserve silence if they desire "sport," and will not suffer even their float to fall heavily into the water.

* These are fully explained in CHAP. X. Sections i. ii.

The *terror* of fishes at loud noises may, it is true, be partly ascribable to feeling; but not so the pleasure they seem to take in musical sounds, a circumstance noticed by the ancients and confirmed by modern testimony.

Osseous fishes have no tympanum, and cannot, therefore, hear in the same way as we do. Their ears consist of a labyrinth of small cavities entirely enclosed within the bones of their head. The sonorous vibrations are imparted from the water to these bones, and thence transmitted to the sensorium.

The *air-bladder* of fishes, in addition to other uses, subserves the purpose of increasing by resonance the intensity of the sonorous undulations communicated from the water to the body of a fish; and, as *dense* air is a better medium of sound than rarefied air, it follows that the lower a fish descends the stronger will be its impression of sound.

Cartilaginous fishes and crustacea (as oysters, lobsters, crabs, crayfish, &c.), have the cavity of the ear prolonged to the surface of the head, where it is covered with an elastic membrane similar to the tympanum of birds and reptiles.

CHAPTER IV.

THE VELOCITY OF SOUND.

Sec. I.—The rate at which sound spreads through atmospheric air.

Effect of wind. Practical applications.

Sec. II.—The rate at which sound spreads through water.

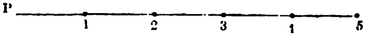
Exp. of Colladon and Sturm.

Sec. III.—The rate at which sound is propagated by solids.

Exp. of Biot. Chladni's tables.

SEC. I. THE RATE AT WHICH SOUND SPREADS THROUGH ATMOSPHERIC AIR.

137. It can be demonstrated by a very simple experiment that sound does not, as light, diffuse itself *instantaneously* to a great distance. Let five men be placed in a **Sound progressive.**



line, 1120 feet apart from each other.

If now a pistol be discharged at P, 1120 feet from the first of these observers, he will see the flash *one second* before he hears the report, the second observer will see it *two* seconds before the report reaches his ear, the third observer *three* seconds, the fourth observer *four* seconds, and the fifth *five*. Why is this? It is because light demands no appreciable time to travel the assigned distance, whereas sound requires *five seconds* to pass from P to the fifth observer.

138. The sound of the pistol will not only reach the several observers at different moments, it will also *cease to be heard* by the first when it reaches the second, and will be inaudible to the second when it passes to the third. So that sound does not spread like a flood of water, but like a ripple made in a lake, which leaves in repose the part over which it has passed.

139. In long files of soldiers, where *two* bands of music are placed at a

considerable distance from each other, it is impossible for the men to *keep step* with both. Every soldier will hear the sounds nearest him before he hears those more remote, and thus the two bands will seem to be playing out of time.

Soldiers marching to music.

140. It is often noticed, too, that if from an eminence any one look upon a long column of soldiers marching to music in front, the various ranks do not STEP *together*. Those in the rear lag a little behind those before them, producing thus a sort of swing or undulation in the whole column. For as each man steps when the sound reaches his ear, those most remote have to wait till the music has travelled to the bottom of the file.

Swing of the file.

141. Take another example: A FLASH of LIGHTNING is seen BEFORE the THUNDER makes itself heard. Without doubt both the flash and the peal begin their course toward the earth at one and the same moment,

Lightning precedes thunder.

but their rate of motion is very different. Thus, while sound is tardily making its way over some thirteen miles of air, light flashes over an enormous distance equal to eight times the entire circumference of our globe at the equator.

Sound travels about a mile whilst a healthy pulse is making five beats. A rough way, therefore, of calculating the distance of a storm, is to count by his pulse the interval between the flash and the thunder-peal, divide the sum by five, and it will give a pretty correct result in miles.

Velocity in air.

142. The average rate at which sound moves in atmospheric AIR is 1120 feet in a second. A warm temperature is, however, somewhat more favourable than a cold one. Thus, if 1120 feet per second be taken as the rate of motion when the thermometer is 60° Fahrenheit, it will not exceed 1090 in a dry frosty air. This diminution of speed is by no means uniform; for the first 10° the difference of velocity being almost in-

appreciable, while from 50° to 32°, the loss of speed is a trifle more than *a foot per second* for every degree which the thermometer falls.

N. B. For all practical purposes 1120 feet per second may be taken as the rate, regardless of temperature.

143. The QUALITY of a sound has no influence whatever on its velocity. Sharp shrill sounds and bass dull ones, the loudest detonation and the softest whisper, all propagate themselves with precisely the same speed. Thus, when several persons at different distances listen to a band of music, they all hear exactly the same tune and the same harmony. It is very true that those at a distance do not hear the notes at the same *instant*, nor with the same *force*, as those nearer to the performers, but nevertheless the *order* of the different notes is undeviatingly preserved, and the harmony unaltered. The whistle of the fife or octave never out-

Rate uniform.

Distant music.

strips the roll of the drum; the tinkling of the cymbals keeps pace with the blast of the trombones; the shrill treble, the melodious tenor, and the deep bass, all preserve a uniform march, an invariable order, and regular succession, to whatever distance the sounds extend.

144. Not only the pitch and loudness of a sound have no effect on its velocity, even WIND has an influence wholly insignificant, inasmuch as sound maintains a rate of motion seven times greater than the swiftest gale that ever blows. Nevertheless, where great accuracy is required, it is customary to *add* the rate of the wind to that of sound when both tend simultaneously toward the listener, and to subtract one from the other when they follow opposite directions.

Influence of wind.

If wind crosses a sound *obliquely*, its effect upon the rate of motion must be calculated in the same way as its

ction on mills and sailing vessels; that s, by what is called the *parallelogram f forces*.

145. The difference of velocity beween LIGHT and SOUND is occaionally made subservient to the dmeasurement of DISTANCES. Thus it is easy to ascertain by approxination the distance of a ship at sea by marking the interval which elapses between the flash and the report of a gun. Suppose the rate of sound to be 1120 feet per second, and the interval between the flash and the report to be 10 seconds, then the ship is (1120 × 10) = 11,200 feet from the observer, or a little more than two miles.* The elevation of a balloon, the breadth of a lake or harbour, the height of a mountain, and the distance of a storm, may all be computed by the same means.

Distance calculated by sound.

* As 5280 feet make a common lineal mile, 11,200 feet equal 2 miles 640 feet.

SEC. II. THE RATE AT WHICH SOUND SPREADS THROUGH WATER.

Experiments of Colladon and Sturm.

146. Sound propagates itself in WATER more than *four times* as fast as it spreads through atmospheric air. This fact has been most satisfactorily demonstrated by Messrs. Colladon and Sturm, in their interesting experiments at the Lake of Geneva already alluded to (117.). A large metal bell was sunk in the lake three feet below the surface, where it was struck by a hammer, so adjusted that when the head struck the bell, the handle struck against some fulminating powder and caused it to explode. This was done that the experimenters, who were seated in a boat 42,336 feet from the bell, might know the exact instant of percussion. In order that they might the better hear the sound underwater, they were provided with acoustic tubes of a peculiar construction. These tubes were made of sheet-iron; to the

bottom was attached a large circular iron plate turned in the direction of the bell, and so arranged that when plunged in the lake its face was perpendicular to the surface of the water. It was found by very careful observation, that *nine seconds* elapsed between the flash and the arrival of the bell-sound through the water; consequently, the sound travelled 4704 feet per second. As the average rate of sound through air is 1120 feet in a second, it is manifest that its speed in water is more than 4 times as fast as in atmospheric air.

Velocity in water.

147. As in air, so in *water* the velocity of sound is somewhat augmented with the temperature. The temperature of the lake, when the experiments were made by Messrs. Colladon and Sturm, was 46° according to Fahrenheit; if it had been 50°, the rate of motion would have been 4864 feet per second.

148. In sea water sound moves even

faster than in fresh; its average rate of motion being 4900 feet per second.

SEC. III. THE RATE AT WHICH SOUND IS PROPAGATED BY SOLIDS.

149. SOLID substances, for the most part, convey sound still more rapidly than water; and, in some cases, with a velocity 14 or 16 fold greater than its rate of motion in atmospheric air.

150. M. Biot* has satisfactorily tested the relative velocities of sound as conducted by air and by metal. A bell was suspended at the mouth of an iron pipe 3000 feet in length, and a metal ring was so adjusted round the orifice, that when the *bell* sounded and transmitted its vibrations

Exp. of Biot.

* Jean Baptiste Biot, astronomer and natural philosopher, was born at Paris, in 1773, and is still living. He was a pupil of Laplace, and assisted Gay Lussac in some of his interesting researches. He has published a large number of works on astronomy, the barometer, mathematics, and physics. One of his best is a treatise, in 4 vols., on *Experimental Physics*.

to the *air* contained in the tube, the *ring* struck against the conduit, and communicated vibrations to its metal walls. In this experiment, the vibrations of the ring conveyed along the sides of the tube, reached the ear of the observer a considerable time before he heard the sound of the bell.

151. The following would be interesting variations of the same experiment, and capable of easy trial. Let some one fire a pistol at one extremity of a long gas-pipe, and the person who applies his ear to the other end will hear the report *twice*. He will hear it almost instantaneously, as it is conducted along the metal walls of the conduit, and again, a considerable time afterwards, as it comes lagging through the ambient air.

Pistol and gas-pipe.

152. Or, again: if at early morning, when the air is calm and the neighbourhood quiet, you apply your ear to one end of the hand-rail of an iron bridge, while some one at the other

Iron bridges.

extremity strikes upon the bar or parapet, you will hear the report of the blow *twice*. The first and loudest will be delivered by the metal, and the second by the air.

N. B. Sound traverses iron somewhat more than 16 times faster than it circulates in air.

The last two experiments could not of themselves be admitted as *proof*, though they may be taken as corroborative evidence of the point under consideration. It will be seen that the circumstances are not equal, inasmuch as the sound-waves have, in one case, the whole field of air, in which to spread in constantly enlarging concentric *circles*, whereas in the latter they can propagate themselves only in *one direction*. In the former case the diffusion is by *squares*, in the latter by *lines*. This objection, however, does not rest against the experiment of M. Biot (150.), inasmuch as the air was confined in a tube. And as the result in

all three cases is exactly the same, the objection is in reality of no valid force.

153. Gay Lussac * has mentioned an analogous phenomenon in the quarries of Paris. If any one strike with a hammer against these rocks, a person standing at the furthest extremity will hear the report conveyed first by the rocks, and then again, after a lapse of some seconds, by the air. Paris quarries.

154. The same observation has been made in blasting rocks in the deep mines of Cornwall. Mines of Cornwall.

155. The rate at which sound is propagated by various solid substances has been carefully tested by Chladni †, to whose observations the following tables are due, in which the velocity of sound in air is taken for unity:— Tables of Chladni.

* Gay Lussac, *see* No. 78. *note.*
† Chladni, *see* No. 135. *note.*

I. Metals.

	Faster than in
Tin	7·50
Silver	9
Brass	10·66
Copper	12
Iron and steel	16·66

II. Woods.

Oak, walnut, yew, and plum	10·66
Pear and red beech	12·50
Maple	13·33
Mahogany, elm, alder, and birch	14·40
Lime and cherry	15
Willow, pine, and white deal	16

III. Promiscuous Substances.

Whalebone	6·66
Tobacco-pipe	10
Ebony	14·40
Glass	16·66

Of all these substances, therefo glass, iron, and steel transmit sou the fastest. Next,—willow, pine, a common deal.

Of metals, tin transmits sound t most slowly; and of woods, oak, waln yew, and plum.

CHAPTER V.

NUMERICAL EVALUATION OF SONOROUS VIBRATIONS.

SEC. I. RELATIVE EVALUATIONS.

156. It has been stated already (63.) that the pitch of a sound depends on the rapidity with which the vibrations succeed each other. If very rapid, the sound produced is exceedingly shrill; if *less* rapid the note elicited is more bass, flat, or grave.

157. The canons of vibrating strings which had engaged the attention of

philosophers for above half a centu

Taylor's canons.

were first established by Brook Taylor *, of Edmont who published his valuable treat called *Methŏdus Incrementum*, in year 1716.

Monochord.

158. These canons were establis by means of an instrument ca a monochord † or sonome which consists of a single string of w or catgut, fixed at one end, and stretc by a weight at the other over a fra The *tension* of the string is increa or diminished by increasing or di

* Dr. Brook Taylor, of Edmonton, Middl died in 1731, at the age of forty-six. He publi numerous treatises; the principal of which are following: *The Stretched String; Methodus I mentum; The Centre of Oscillation; The Ascen Water between two Glass Planes; Magnetic Attrac* and *Linear Perspective.*

† The invention of a monochord, to show th tervals between different notes, is due to the fa Pythagŏras, who flourished about 500 years b the Christian era. Claudius Ptolemy, the celebr astronomer, measured and proved by it all his tervals. The monochord now generally employ a modification of the same instrument by Savart

nishing the weight attached to it; and the *length* of the vibrating part is varied by means of a moveable bridge on which the string rests.

159. Suppose the string of a monochord adjusted for any given note, and you require to produce its *octave:* this may be accomplished in three different ways: (1) By shortening the string; (2) By stretching it with a greater weight; and (3) By employing another string less heavy. If the *first* of these plans be adopted, you must shorten the string *one-half.* If the *last,* you must use a string of *half* the weight. If the middle plan be preferred, the weight employed to stretch the string must be *four times* as heavy as the former. Stretched strings.

§ 1. *First Canon of the stretched String.*

160. THE VIBRATIONS OF STRETCHED STRINGS ARE IN INVERSE PROPORTION TO THEIR LENGTHS, or, in other words, as a string is *lengthened* it 1st Canon.

vibrates more slowly and produces a graver note; as it is *shortened* it vibrates more quickly and renders a higher note.

Relative length of each string.

161. The diminution of length needful in order to obtain the successive notes of an octave is not the same for any two intervals. If a string 180 lines* long give the C of any octave, it must be shortened 20 lines in order to obtain D, 16 more to produce E, only 9 more for the next note F, 15 more for G, 8 for A, and 12 for B. Supposing the length of the string in the first instance to be one yard or one foot, it will be found by the monochord that the relative lengths of string for the seven successive notes will be as follows:

RELATIVE LENGTH OF EACH STRING.

C	D	E	F	G	A	B	C octave.
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

These numbers also denote the comparative lengths of organ-pipes.

* 180 lines = 15 inches. A line is the unit of length.

That is, if a string 1 yard or 36 inches long give C, in order to produce D it must be $\frac{8}{9}$ths of a yard or 32 inches; in order to produce E it must be $\frac{4}{5}$ths of a yard or $28\frac{1}{5}$ inches; in order to produce F it must be $\frac{3}{4}$ths of a yard or 27 inches, &c., and in order to produce the octave it must be exactly half its original length.

162. The above scale of notes is named the *diatonic scale.* The lowest note of the scale is termed the *fundamental*, *tonic*, or *key*-note; the others in succession are called the *second*, *third*, *fourth*, *fifth*, *sixth*, and *seventh.* Thus in the scale of C, E is the *third*, G the *fifth*, and so on. The fifth note is also called the *dominant*, and the third the *mediant.* The fourth is the *sub*-dominant, and the sixth the *super*-dominant. Similarly the note next before the tonic is called the *sub*-tonic, and that

* Diatonic is compounded of two Greek words, δια τόνος (*by tone*); *i. e.* a scale consisting of tones, or made *by tones.*

which immediately follows the toni
the *super*-tonic. Thus

NAMES OF THE NOTES OF A SCALE.

1st Fundamental or Key-note.	2nd	3rd	4th	5th	6th	7th	Oct
Tonic.	Super-tonic.	Mediant.	Sub-dominant	Dominant.	Super-dominant	Sub-tonic.	Tonic

163. As the number of vibration from different strings is alway in *inverse proportion to thei length*, the relative number c vibrations of any given octave may b obtained by inverting the fractions c the table on page 108. Thus:

Relative number of vibrations.

RELATIVE NUMBER OF VIBRATIONS.*

For C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Fundamental, or Tonic.		Third, or Mediant.		Fifth, or Dominant.			Octave

* Those who find it difficult to understand th proportions of fractional quantities may, perhaps, ob tain a more distinct idea of these relative vibration by the following whole numbers.

For	C	D	E	F	G	A	B	C
Rel. vib.	24	27	30	32	36	40	45	48.

That is, in the time that C is making 8 vibrations D makes 9; in the time that C is making 4 vibrations E makes 5; in the time that C is making 3 vibrations F makes 4, &c.; and in the time the fundamental note makes 1 vibration, its octave makes 2.

164. It will now be readily understood why the STRINGS of a harp or of a pianoforte DIFFER in LENGTH; and why their difference of length is not *uniform*. Harp strings differ in length.

165. It will also be evident that the performer on a violin, violoncello, and guitar, SHIFTS the FINGERS of his left hand at unequal distances along the several strings, in order to increase or diminish the vibrating part to the length corresponding with the note required. Violinists shift their fingers.

In *tuning* a violin, the player rarely depends

From which it appears that, for every 24 vibrations made by C (the fundamental note), D makes 27, E 30, F 32, &c., and the octave 48.

entirely on his ear. He more frequently places his finger on such a part of the next lower string as to leave *two-thirds* between the bridge and his finger, and *one-third* between his finger and the nut; by this means he so stops the string that the vibrating part is to the *entire length* as 2 to 3. If now the next higher string yields exactly the same note as the shortened one, they are *both in tune*, because the strings of a violin are tuned in *fifths*, that is, the whole length of the *second* string yields a note which is the major 5th of the bass string; the fundamental note of the *third* string is the same as the major 5th of the second; and the whole length of the treble string yields the same note as *two-thirds* of the third string. By turning to the table (161.) under letter G, which is the fifth from C, will be found the fraction $\frac{2}{3}$, showing that the ratio of length between a fundamental note and its major fifth is as 2 to 3. If, therefore, a lower string be so stopped as to be only $\frac{2}{3}$ of its entire length, it will yield the major fifth, or the same note as the entire length of the string next above it.

§ 2. *The Second Canon of the stretched String.*

166. THE VIBRATIONS OF STRETCHED
2nd Canon. STRINGS ARE IN PROPORTION TO

THE SQUARE ROOT OF THEIR TENSION.* If the string of a monochord stretched by the weight of 1 lb. render a certain number of vibrations in a second, and you wish, without altering its length, to obtain from the same string the octave, a note which gives *twice* the number of vibrations in the same time, you must change the weight for one of 4 lbs. If, again, you would obtain from the same string the *double* octave, which makes *three* vibrations for one of the fundamental, you must apply a weight equal to 9 lbs. If you wish to procure from the same string, without altering its length, the *triple* octave, a note which vibrates *four times* as fast as the fundamental, you must attach to the end a weight of 16 lbs., and so on.

167. Hence it may be perceived that

* The square of 1, 2, 3, 4, 5, &c.
is 1, 4, 9, 16, 25, &c.
The square root of 1, 4, 9, 16, 25, &c.
is 1, 2, 3, 4, 5, &c.

the *tighter* a string is drawn, the *faster* it vibrates, and the sharper or higher its pitch. On the other hand, the *looser* a string the *slower* its vibrations, and the flatter or graver the note which it renders.

Relation between pitch and tension.

168. This axiom is practically familiar to every one who has seen a violinist *tuning his instrument.* When any string is too *flat,* he screws it up tighter; when too *sharp,* he relaxes it a little. Harps, guitars, pianos, and all other stringed instruments, are tuned on a similar principle.

Tuning stringed instruments.

169. In a concert, it is customary to tune the instruments employed not only when the performance commences, but again at the beginning of the Second Part. This arises from the hot vapour of the room, which has a different effect upon different instruments. It relaxes all *metal strings,* rendering them too *flat,* but makes all *wind instruments* and *catgut* strings somewhat too sharp.

Tuning instruments in a concert.

Hence pianofortes can rarely keep together with violins and wind-instruments during a concert.

The hot breath of the performers has probably more influence upon wind-instruments than the mere vapour of the concert-room (298.)

170. METAL strings are generally a little too SHARP in dry FROSTY weather, because the cold condenses them and increases their tension. In hot summer weather, they are somewhat too flat. On the other hand, CATGUT strings become more tightly twisted in dry weather, and as their length is thus increased, their tension is less and their pitch more flat. Humidity has the contrary effect; by insinuating between the fibres it untwists the catgut, shortens the length of the string, and renders it of course more sharp.

Influence of weather on strings.

As catgut is shortened in damp weather and lengthened in dry, it is not unfrequently employed to indicate the hygrometrical state of the air.

§ 3. *The Third Canon of the stretched String.*

3rd Canon. 171. When strings have the same length and tension, but differ in *weight* or thickness, their VIBRATIONS ARE IN INVERSE PROPORTION TO THEIR WEIGHT. If a given string make a certain number of vibrations in a second, another *twice as heavy* will, under similar circumstances, give only *half* the former number of vibrations in the same time; one *thrice as thick* will make *one-third* as many; and one *four times as heavy* will render only *one-fourth* the number of the first string. This canon may be easily remembered, because a fraction, having unity for its numerator or top figure, and the relative weight for its denominator or bottom figure, will represent the relative number of vibrations made by any given string. Thus if a string of a given length weigh 1 ounce, another which weighs 2 ounces will make $\frac{1}{2}$ the num-

ber of vibrations; a third which weighs 3 ounces will make $\frac{1}{3}$ the number of vibrations; a fourth which weighs 4 ounces will make $\frac{1}{4}$ as many; and so on.

The same rule applies to the first canon, only *length* must be substituted for weight.

172. This law finds an illustration in the common practice of making BASS strings of musical instruments THICKER or of a heavier material than the treble ones. Sometimes a metal wire is coiled round the lower strings of a harp or piano to increase their weight. Sometimes different metals are employed, as copper, brass, and steel, the heaviest metal being always made to represent the lowest note. Of all materials the best adapted to bass notes is *platinum* wire, then gold, then silver, then copper, then brass, then steel, then silk; catgut, the last of the series, being best suited for treble notes. When catgut and silk are *enfilated*, that is twisted

Bass strings.

with a coiling wire, their tone will be depressed in proportion to the weight of the metal employed.

The *lowest* bass notes of a piano-forte are generally made of *brass* covered with copper wire, the *medium* bass-strings of *steel* covered with copper wire, the *upper* bass of brass wire without any coil, and all the rest of the strings of steel.

SEC. II. POSITIVE EVALUATION OF SONOROUS VIBRATIONS.

173. The monochord or sonometer serves only to determine the *Relative* number of vibrations corresponding to the eight successive notes of an octave; but M. Savart*, whose experimental investigations have thrown so much light upon the physics of sound, in-

* Felix Savart was born at Mezières, in France, and died at the age of fifty, in the year 1841. This celebrated natural phoilsopher has acquired an European reputation for his ingenious and successful researches in the science of acoustics, and for the invention of several instruments to demonstrate the actual numerical value of vibrations corresponding to any given sound.

vented a very simple machine for the purpose of determining the *actual* number of vibrations made in a second by any given note.

174. His apparatus for this purpose is simply a wooden frame with two wheels. The larger one, turned by a winch, being furnished with what is technically termed *an endless band* to connect it with the axis of a small toothed wheel. When the machine is put in motion, these teeth strike against the edge of a card or thin plate of metal, and produce sounds corresponding in pitch to the velocity with which the wheel revolves.

Savart's apparatus.

If any one desire to make such a machine, let his model be a knife-grinder's apparatus, with toothed wheels in the place of grindstones. The card can be very easily adjusted.

175. As each tooth causes the card to vibrate once, it is easy to ascertain the exact number of vibrations corresponding with any sound produced, merely by counting the number of

teeth which have struck against the edge of the card or elastic plate.

176. By means of this apparatus it has been ascertained that the "pitch note" of an orchestra, which is A

Pitch A.

in the treble clef, is produced by 853 vibrations in a second.

Tuning-forks differ a little in pitch. The one Savart tested was the tuning-fork employed in the French Opera-house at Paris.

177. Having ascertained the numerical value of this one note, and knowing the relative value of the rest (163.), the actual number of vibrations made in a given time by each note of the gamut may be determined by simple multiplication and division.

178. Suppose, for example, you wish to know the actual number of vibrations necessary to produce C of the same octave as the pitch note. You first search for the fraction which expresses the value of A. This you find (163.) to be $\frac{5}{3}$. As you want a

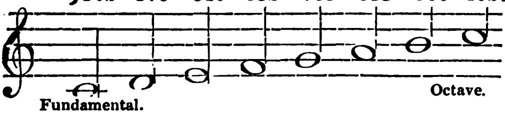
Vibrations of C_3.

lower note you must multiply by the *smaller* number and divide by the larger. Thus: 853 × 3 ÷ 5 = 512, the number of vibrations which produce the C in question.

179. In a similar way every other note may be calculated. Let us take the C already found for our starting point, and ascertain the exact value of the seven successive notes. They will be as follows.*

Tone of C_3.

No. of Vibrations.	C	D	E	F	G	A	B	C
	512	576	640	682	768	853	960	1024



In order to find these numbers, you must seek (163.) the fractions which respectively represent them, then multiply 512, the number given, by the *larger* or upper figure, and divide by the smaller or *lower* figure of the fraction.

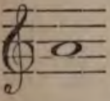
* Erard's seven-octave pianofortes extend three octaves below and four octaves above this scale, which contains the orchestra key-note.

Tones of C_2 and C_4.

180. By *halving* the numbers of one scale we obtain the numerical value of the octave *below*, and by *doubling* them we have the number of vibrations made by the notes in the octave *above*.

Unit tone.

181. In physics it is customary, for the sake of being more explicit, to call the scale which contains



the pitch A the unit tone*, and to designate it thus, C_1. The notes in the clause 179. belong to this scale. The octaves below are respectively designated C C_{-1} C_{-2} C_{-3}. The octaves above are C_2 C_3 C_4 C_5 &c.

* Tone here means the series or family of seven notes belonging to any given tonic or base.

182. TABLE OF ACTUAL VIBRATIONS CORRESPONDING TO EACH NOTE OF A SEVEN-OCTAVE PIANO.

	C	D	E	F	G	A	B	
C_{-3}	$32=2^5$	36	40	43	48	53	06	
C_{-2}	$64=2^6$	72	80	85	96	106	120	1st Octave
C_{-1}	$128=2^7$	144	160	170	192	213	240	2nd Octave
Middle C	$256=2^8$ 264 Stuttgart	288	32	341	384	426	480	Mid. C 
C_1	$512=2^9$	57	640	682	768	Pitch A 853	960	pitch A 
C_2	$1024=2^{10}$	1152	1280	1365	1536	1706	1920	5th Octave
C_3	$2048=2^{11}$	2304	2560	2730	3072	3413	3840	6th Octave
C_4	$4096=2^{12}$	4608	5120	5461	6144	6826	7680	7th Octave

Consequently the lowest C of a seven-octave piano makes 32 vibrations in the same time that its highest C makes 4096.

N.B. The table given in the previous page is made for *single* vibrations; those who prefer to consider one condensation and one rarefaction as composing a perfect vibration or sound-wave must divide each number by 2.

183. To obtain the numerical value of a *sharp*, you must multiply the natural note by 25 and divide by 24. To obtain a *flat* you must multiply by 24 and divide by 25. Whence it appears that while the *tonic* makes 24 vibrations, its *sharp* makes 25; and that while the tonic makes 25 vibrations, its *flat* makes only 24.

Sharps and flats.

SEC. III. PHYSICAL CAUSES OF CONCORD AND DISCORD.

184. Certain musical combinations are agreeable to the ear and pro-

duce harmonious sounds, while certain others are disagreeable and produce discords.

185. Of the former sort are the unison, third, fifth, and octave. The second and seventh are *discords.* Concords and discords.

186. Musical sounds may be compared to a series of dots equidistant from each other, thus: Sounds represented by dots.

● ● ● ● ● ● ● ● ●

The smaller the interval between these dots or pulses, the higher the tone; and the greater the interval, the lower or graver the note.

If the distances between the dots be not *equal,* or if the dots be irregularly scattered, they represent a confused or unmusical sound.

187. To represent two simultaneous tones, it will be needful to draw *two* dotted lines, one below the other; and the most pleasing combinations of sounds will be represented by Unisons.

those lines in which the dots of one most frequently accord with those of the other. Thus an *unison*, which is composed of two tones of identical vibrations, may be represented by two lines of equi-distant dots, thus:

● ● ● ● ● ● ● ● ●
● ● ● ● ● ● ● ● ●

Concords. Discords.

188. When the difference between the beats or vibrations of two notes is in a low ratio, so that the ear can readily discern the relation between them, the ear is pleased, and we call the combination a *concord;* but if the synchronisms of the two series of vibrations are so few and far between that the ear cannot easily detect them, it is dissatisfied, and we call the combination a *discord.*

The following are the most important concords:

Octaves.

189. OCTAVES, in which the lower note makes *one* vibration, while the upper makes *two.* In this

combination, the beats chime together in the proportion of 1 to 2. Thus:—

● ○	● ○	● ○	Octave.
● —	● —	● —	Fundamental.

190. The next most perfect combination of sounds is that of the fundamental and its MAJOR FIFTH, as when C and G are sounded together. By turning to the table (163.), the fraction $\frac{3}{2}$ will be found under the letter G, which means that G makes 3 vibrations while C makes 2. Thus:

Major 5th.

● ○ ○	● ○ ○	● ○ ○	G
● ○	● ○	● ○	C

Here each *alternate* vibration of the fundamental note coincides with the harmonic; consequently this concord is only half as full as the octave.

191. In MINOR FOURTHS, the lower

Minor 4th. note makes 3 vibrations while the higher makes 4. Thus:—

● ○ ○ ○ | ● ○ ○ ○ | ● ○ ○ ○ | F
● ○ ○ | ● ○ ○ | ● ○ ○ | C

After every coincidence, therefore, the lower note of this chord makes *two*, and the upper note *three* vibrations, which do not coincide or beat together.

192. The SIXTH, as when C and A are sounded together, is called an imperfect chord, because it may be made with either a major or a minor interval. The relative vibrations of these two notes are 3 to 5. Thus:—

Sixth.

● ○ ○ ○ ○ | ● ○ ○ ○ ○ | ● ○ ○ ○ ○ | A
● ○ ○ | ● ○ ○ | ● ○ ○ | C

The synchronisms of this chord are, therefore, very little less numerous than those of the minor fourth.

193. The last chord is that of THIRDS, which is also *imperfect* or alterable to either the major or minor interval. Of the two the major mode forms the better chord, the relative vibrations being in the proportion of 4 to 5. Thus:—

Thirds.

● ○ ○ ○ ○ | ● ○ ○ ○ ○ | ● ○ ○ ○ ○ | E
● ○ ○ ○ | ● ○ ○ ○ | ● ○ ○ ○ | C

Here every coincident beat is followed by three vibrations of the one note and four of the other, which do not time together. The *minor* third, being in the proportion of 5 to 6, is inferior in synchonous beats to the major.

194. Mark now the difference between the preceding harmonies and what are called DISCORDS; and it will be seen that the beat of the former vibrations may be likened to the regular tramp of an army on the march, while those of the latter are as confused as the noise made by the feet of a tumultuous crowd.

Discords.

Seconds and sevenths.

195. In analysing discordant sounds, it will not be needful to go into detail, but merely to state that the beats of SECONDS coalesce in the remote proportion of 8 to 9, and those of SEVENTHS in the still feebler ratio of 8 to 15. (*See* No. 163.)

Full chords.

196. The same synchronism of vibrations which renders two concordant notes so agreeable, makes a FULL CHORD pleasing and harmonious. Take, for example, the most complete chord in harmony composed of the fundamental, third, fifth, and octave, as the chord of F, composed of F, A, C, and the octave; the chord of C, composed of C, E, G, and the octave; and the chord of G, composed of G, B, D, and the octave. In every case the number of vibrations may be reduced to the formula 4, 5, 6, and the octave; which means, while the fundamental note of the chord makes 4 vibrations, the second note makes 5, and the third note 6. Consequently, the beats of

the two octave notes coalesce in the proportion of 1 to 2 ; those of the first and third in the proportion of 2 to 3 ; those of the third and octave in the proportion of 3 to 4 ; and the second note synchronises with all the others in every 5 beats, after the following manner:

● ○ ● ○ ● ○ ● ○	● ○ ● ○ ● ○ ● ○	8th
● ○ ○ ● ○ ○	● ○ ○ ● ○ ○	5th
● ○ ○ ○	● ○ ○ ○	3rd
● ● ● ●	● ● ● ●	1st

The black dots indicate the coincident vibrations.

N.B. A perfect *major* chord consists of the tonic or fundamental, the major 3rd, a just 5th, and the octave. By lowering the 3rd of the major chord a semitone, we obtain the *minor*, which consists, therefore, of the tonic, the minor 3rd, a just 5th, and the octave.

197. The DOMINANT SEVENTH is, after the perfect common chord, the most important in harmony. It consists of four notes and the octave, viz., the fundamental, major third, just fifth, Dominant chords.

and minor seventh. Hence it will be seen that a perfect major chord becomes a dominant by the addition of the *seventh.* It will be found on trial that the additional note is a little refractory, and that, therefore, the synchronisms of the *dominant seventh,* though sufficiently numerous to be agreeable, are less so than chords composed of *three* notes and the octave.

This chord is called *dominant,* because the bass note is always the 5th or dominant of the tonic. It is called *seventh,* because an interval of the seventh separates its extreme notes. There are in music *nine* varieties of this chord, in eight of which the seventh is *minor.* There are two chords (*the major and minor ninths*). composed of *five* tones. These chords are the same as the dominant seventh with the addition of another note taken from the superior octave. The additional note is the *ninth* from the fundamental ; and, consequently, a *dominant ninth* consists of the fundamental, major third, just fifth, minor seventh, and ninth.

The reduction of the several vibrations made by the respective notes of a perfect *major* chord into the formula 4, 5, 6. and the octave, as mentioned above (196.), will be manifest from the fol-

lowing proof. According to the note subjoined at the foot of page 110., the relative numbers of vibrations of any eight successive notes are as follows:—

For	C	D	E	F	G	A	B	C
Vibrations	24	27	30	32	36	40	45	48
	Fund. or Tonic.		Third or Mediant.		Fifth or Dom.			Octave.

The chord of F = F A C_2
(*Reduce by* 8.) 32 40 48 = 4 5 6.

The chord of C = C E G
(*Reduce by* 6.) 24 30 36 = 4 5 6.

The chord of G = G B D_2
(*Reduce by* 9.) 36 45 54 = 4 5 6.

Another curious fact is that the three major chords referred to above furnish of themselves all the eight notes of the diatonic scale, C, D, E, F, G, A, B.

Every other chord of the scale requires a *sharp* to render its third *major*.

SEC. IV. ACTUAL SIZE OF SOUND-WAVES.

198. Knowing the number of vibrations which correspond to any given sound, and the rate of motion at which sound travels, it is easy to determine

the exact size of any particular wave by dividing its rate of motion by the number of its vibrations.

Rule. 199. Thus, suppose sound to travel in air at the rate of 1120 feet per second, and you wish to know the amplitude of the sound-waves proceeding from the "pitch-note" of an orchestra, or A in the treble clef; you must first turn to the table (182.) to ascertain the number of vibrations made by the required note, which you will find to be 853 per second. Divide 1120 by 853, and the quotient will be the length of the wave required one second after it has been created.

200. The length of the waves producing C_{-3} is found by dividing 1120, the velocity of sound, by 32; the result is 35 feet, which is just the length of an open organ-pipe capable of sounding this note. The next note C_{-2} would be produced by a pipe of half the length, or $17\frac{1}{2}$ feet; middle C, which is produced by 256 vibrations in a

second, by a pipe $4\frac{3}{8}$ feet; and the highest note C_5 by one a little more than an inch-and-a-half.

201. It appears from the experiments of Despretz that the limit of perceptible sounds depends only on the force necessary to make the organ of hearing vibrate, and that even two vibrations are sufficient to characterise a sound. Such a sound must, of course, be exceedingly grave, being four octaves lower than the lowest C of a seven-octave piano. Limits of sound.

202. The highest or shrillest sound appreciable by the human ear, according to the same authority, corresponds to 73,000 vibrations in a second. The amplitude of the waves made by the *former* after a second is 560 feet; of the *latter* considerably less than the *fifth part of an inch.**

* This wave is $\frac{336}{1875}$th of an inch; the *fifth* of an inch $=\frac{375}{1875}$. So that the wave in question is less than the fifth of an inch by the $\frac{39}{1875}$th part.

203. The most ingenious application of acoustic instruments has been that of the "SIREN*," to calculate the number of vibrations necessary to produce the buzzing, droning, and humming of *insects*. It has been ascertained that the noise made by a GNAT proceeds from a muscular action of its wings, which produces the enormous number of 15,000 vibrations per second. Comparing this with the highest note of a 6¾ octave piano, which

Buzz of gnats.

* The Siren, invented by the ingenious M. Cagniard de Latour in 1819, consists chiefly of two perforated plates parallel to each other.

The lower plate, P P, is fixed; and the upper one, *p p*, which does not *touch* the lower, turns freely on a vertical axis, A. A jet of water, thrown obliquely through the lower plate, sets the upper one in motion; which, in moving, covers and opens alternately the holes of the lower plate, producing a musical sound corresponding in shrillness to the rapidity of the rotation. The velocity is regulated by the force of the jet; and the number of rotations are marked by the clocks.

is A_3 and gives 3413 vibrations in a second, we find the pitch of the "gnat's trumpet" is more than two octaves higher. The chirp of the cricket, and the cry of the grasshopper, are the results of a still more rapid succession of vibrations, while the hissing noise of some of the serpent tribe has been computed to proceed from the almost incredible number of 24,000 vibrations in a second.

CHAPTER VI.—PART I.

VIBRATING MUSICAL INSTRUMENTS.

Sec. I.—Stringed instruments.
  § 1.—Played with a bow.
    Ex.—Violin, viola, violoncello, double bass.
  § 2.—Struck with the fingers.
    Ex.—Harp, guitar.
  § 3.—Struck with hammers.
    Ex.—Pianoforte.
Sec. II.—Instruments with metallic tongues.
  Ex.—Musical snuff-box, Jews'-harp, Repeater.
Sec. III.—Instruments of percussion.
  § 1.—Those which ring.
    Ex.—Tuning-fork, bell, musical glasses, triangle, cymbals, gong.
  § 2.—Those furnished with an elastic membrane.
    Ex.—Drum, Tambourine.

204. Musical instruments may be classified under four grand divisions: (1) *Stringed* instruments; (2) Instruments with *metal tongues* or reeds; (3) Instruments of *percussion;* and (4)

Wind instruments. Each of these classes contains two or more distinct species.

SEC. I. STRINGED INSTRUMENTS.

205. Stringed instruments may be ranged under three heads: (1) those played by a *bow*; (2) those struck by the *fingers*; and (3) those struck by *hammers*.

§ 1. *Stringed Instruments played by a Bow.*

206. The most important of these, and the prince of all instruments, for the concert-room is the VIOLIN. Made to obey the touch, it speaks the impulse of the genius which awakes it. At one time simple and melodious, it charms the hearer with its touching harmony and pastoral simplicity. At another time, animated and enlivening, it excites the spirit and leads the dance. In the hands of a

Violin.

Viotti* it dives into the heart with its grandeur, fire, and audacity; under the bow of a Tartini † it is plaintive and full of grace. Let a Corelli ‡ touch it and it charms the audience with its melody; let Gaviniés § bid it speak, and it is the soul of sweetness; with a Pugnani ‖ it is wild, noble, and sublime. It can be pathetic under the fingers of one

* J. B. Viotti was the first violinist of his age. He was a Piedmontese, who settled and died in London, 1824, aged sixty-nine.

† Giuseppe Tartini was the son of a wealthy Italian who died at Padua, 1770, aged seventy-eight. He was the author of a vast number of musical pieces.

‡ Arcangelo Corelli, a native of Fusignano, in Italy, the founder of a school of violinists, died 1713, aged sixty. He was the best performer on the violin of his age; and his work, called *Opera quinta*, is indispensable as an elementary work to that instrument.

§ Pierre Gaviniés, the celebrated violinist, was born at Bordeaux, in France, and died 1800, aged seventy-four. At the age of fifteen he gave a concert at Paris, and electrified the audience by his extraordinary talent. He may be called the founder of the French school of violinists.

‖ Gaetan Pugnani, founder of the Italian school of violinists, was born at Turin, in Italy, and died 1803, aged seventy-six. The King of Sardinia appointed

master, trifling under those of anothe and grand under the touch of a thirc No instrument known to man is so ca pacious, so diversified in its characte so magic in its influence. It can excit or soothe, be gay or be sublime, ca lead or follow, sustain or attenuate it sounds, bear a single role or take par in a full band.

207. Such is the violin. The instru ment itself consists of a shell composed of two tables joined together by bands of beech-wood. The upper table or sounding board is made of deal, or of some ver dry, elastic wood, entirely free fror sap. The under table or back of th violin is generally of beech. The fou strings are of catgut; fixed at the uppe end into a slip of horn; then throw over a bridge; and, after traversin the neck, stretched by pegs to thei proper tension.

Construction of violins.

him first violin in his chapel, and director of h concerts.

208. The strings are occasionally struck by the finger, but are more frequently excited by a bow. When inflected by the finger, their vibratory motion may be seen by the naked eye; the effect from the bow is not so palpable; but that similar vibrations are established may be demonstrated by the following means: Place a few slips of paper astride one of the strings, and as soon as the bow is drawn across it, they will be thrown into such agitation that most, if not all of them, will be dislodged.

Played by a bow.

209. The hair of the bow is *rosined* in order to increase its friction. As the bow is drawn along, the hair sticks to the string over which it moves, giving it a series of little twitches, each of which produces a vibration. And as these twitches are repeated so long as the bow continues its friction, the vibrations are renewed and the sound sustained.

Rosined.

210. It may, perhaps, appear re-

markable that musical sounds, created by a series of *jerks*, should nevertheless be smooth and continuous, as if each note were the effect of a single vibration, instead of being composed of numerous little beats, pulses, or throbs. This arises from the constitution of our organ of hearing. When the drum of the ear is struck, the effect continues for the *twelfth part of a second* after the blow has ceased * ; if, therefore, sound-waves follow so rapidly as to succeed each other at smaller intervals of time than the twelfth of a second, the impression of the previous impulse will be renewed before the sensation has had time to subside. In an analogous manner, a stick burnt at one end moved backwards and forwards with rapidity, appears to make a continuous line or circle of light.

Sound continuous.

* So also the effect of a blow on a common drum continues after the drumstick has been removed from the head.

211. It may not be uninteresting to draw attention to certain minutiæ in the *construction* of violins, which seem at first sight of minor importance, but which, nevertheless, perform their role in the general effect produced. In the first place, it is not without design that the strings are inserted into a *slip of horn or whalebone*, called the *queue*, attached to a button in the head of the instrument. The object of this arrangement is to *stop the vibrations* at this particular part. The queue cannot propagate the vibrations of any one string by reason of the counteracting and unequal tensions of the others; a reaction, therefore, takes place upon the bridge, the agitation of which is proportionably increased.

Violin explained.

212. The vibratory motion of the strings causes the BRIDGE to tilt or *dance on the face of the violin*, and communicate to it corresponding vibrations. These vibrations are next

Violin bridge.

impressed on *the air in the body of the instrument*, and thence to the *back-board.*

213. Between the face and back a *small prop* is placed under the right foot of the bridge. The object of this prop, called the sound-post or "soul" of the violin, is not so much to support the "belly" under the pressure of the strings, as to make the face and back vibrate in exact unison. Much of the beauty of the instrument depends on the precise position of this post.

Soul of a violin.

214. Hence it appears, that not only the strings, but the bridge, the face, the sound-post, the back, and all the air contained in the body of the violin, contribute to produce the sound elicited, and, by vibrating in unison with each other, to increase its volume. If, indeed, only the *strings* vibrated, the air would be struck by such a *fine line*, that the force of the shock would be insignificant; but when a large surface, such as the

Frame vibrates.

entire body of the violin is set in motion, the impulse is sufficient to produce sounds of considerable power.

215. The face of a violin is curved, and the waist bowed inward, to give room for the play of the bow upon the two outside strings.

Shape of violins.

216. A dancing-master's KIT contains strings like those of a violin, but its sounds are as feeble as its size is insignificant. On the other hand, the lower notes of a DOUBLE-BASS are at times sufficiently powerful to shake the benches of a theatre or concert-room.

Kit and double bass.

217. As the materials of the instrument itself contribute so greatly to the sound, the texture, nature, and quality of the wood employed must be exceedingly important. If from any cause the *body* of a violin will not vibrate in unison with the strings, antagonistic vibrations will be established, and the effect produced will be disagreeable as that

Material of the frame important.

of a cracked bell. Green wood is especially improper, as the sap and various degrees of dryness in the different molecules must effectually prevent uniformity of vibration.

218. There can be little doubt that the old Cremōnas* or Amatis† owe their unrivalled excellency more to the nature and antiquity of the wood of which they were made, than to any secret peculiarity in their construction. Certain is it that all violins improve with age, and that the gradual change wrought in them by wear and tear, as well as by the continual agitation of their molecules, is

Cremonas.

* Cremōna is a general name given to violins made at Cremona, the capital of Milan, in Italy, between the years 1700 and 1722, by the Amati family and a pupil named Stradivarius.

† Amati, his pupil Stradivarius, his two sons Jerome and Anthony, together with his grandson Nicholas, were all violin makers at Cremona, whose instruments were never equalled.

Next to the ancient Cremonas, the violins made by Jacob Steiner, and those by two Tyrolese named Klotz, are the most esteemed.

favourable to their sweetness and to their purity of tone.

219. The same observation is applicable to pianofortes and to *organ-pipes*. The main reason why the organs of one builder are so superior to those of another, is chiefly owing to the skill with which the materials are selected. A slight and almost imperceptible difference in the alloy of an organ-pipe, or some almost indiscernible difference in the grain, state, or quality of the wood employed, will suffice to depreciate or enhance the value of an organ to an almost incredible amount.

Organ-pipes.

220. Violinists have the power of damping or subduing the sound of their instruments by placing astride the bridge a piece of metal called a *sourdine** or mute. The effect

Sourdine.

* Sourdine, from the French "sourd," *deaf* or *dull*. Sourdines are sometimes made of box-wood, sometimes of ivory or silver, but most frequently of brass.

of this clasp is to prevent the tilting or dancing of the bridge, and its consequent communication of vibrations to the body of the violin. Its action is in some little measure due to its weight; in some measure also to its inability to sympathise with any one string in consequence of its free position amongst them all; but more especially to its *pressure*, by means of which the uniform density of the bridge is interrupted, and its vibrations interfered with.

221. The VIOLA or "tenor" is in size and pitch between the ordinary violin and the violoncello. It has four catgut strings, of which the third and fourth are covered with silver wire to increase their weight. It is tuned C, G, D, A, reckoning upwards, exactly an octave higher than the violoncello, and a fifth lower than the violin, which is tuned G, D, A, E. The Viola is essential to fill up the void which would otherwise exist between

Viola.

the second violins and the bass. introduces an harmonious mean, ar augments considerably that "body tone" which constitutes the richness concerted music.

222. Of instruments played with tl
Violoncello. bow, the next in importance the violin is the VIOLONCELL It was invented at the beginning of tl 17th century by an ecclesiastic nam Tardieu, and was originally mount with 5 strings; the second D-strii was, however, soon retrenched, ar the instrument reduced to its prese form.* By nature the violoncello noble, majestic, grave, and touchin but, like the violin, it takes its colo from the genius of the person wl plays it. It forms an essential acco paniment to an orchestra, and ca express also, with considerable effect, solo, sonata, or a national air.

* It was reduced to its present form in 1727, Buonocini, master of the chapel of the king Portugal.

As far as the science of physics is concerned, the observations already made respecting the violin may be applied generally to the viola, the violoncello, and to all other instruments of the same family.

223. The strings of a violin, viola, and violoncello, are tuned in *fifths* from each other; those of the *double-bass* are generally tuned in *fourths.** The lowest note of a violin is G below the second under-line of the treble staff; from this point a tolerably skilful player has at his command a scale of *three octaves and a sixth.* Music for the violin is written in the G or treble clef. Scale of the violin, &c.

Each of the four strings of a violin, G, D, A, E, is reckoned to have a scale of two octaves or 15 notes; but, in reality, the skill of the performer alone sets the limits of his instrument.

* Such at any rate was the custom of Dragonetti and Aufossi, though some other musicians adopt a different arrangement.

224. A VIOLONCELLO has also 4 cat-gut strings, called C, G, D, A. The first two are covered with *silver wire* to increase their weight. The compass of this instrument is reckoned to be somewhat more than *four octaves*, beginning from double C, and extending to the highest E obtainable on the violin.

Scale of the violoncello.

225. The DOUBLE-BASS has three strings; but in Germany a fourth is generally added. The notes are for the most part written in the bass clef an octave higher than they are played. Its scale is about 11 notes, the first of which is an octave below the double C of a violoncello.*

Scale of the double bass.

226. Before quitting the subject of violins we would subjoin a few remarks upon their peculiarly fanciful and expensive SHAPE. According to the experiments of Mons.

Shape of violins.

* The double-bass is sometimes tuned C, F, B; and sometimes A, D, G.

Savart* in 1819, a simpler form would be at once more economical and equally efficient. For example, if the two holes cut in the face of these instruments in the shape of an S were parallel, square, round, or oblong, the air in the body of the violin would more freely communicate its vibrations to the external air.

Bar of harmony.

The position of the bar, commonly called the *bar of harmony*, running along the under-surface of the face, for the purpose of strengthening it and intercepting the longitudinal vibrations, is decidedly ill-arranged. It is placed a little on one side of the axis or middle line of the instrument, and the sounding post is fixed at a similar distance on the other side of the axis. According to Savart, the bar of harmony ought to be placed exactly along the central line, in order to equalise the vibratory power on each side.

* Savart, see notice at the foot of page 118.

Violin waist.

Again, the *contracted waist* of violin, and the curve of the fa and back, may perhaps serve give the bow more liberty of actio but certainly interrupt the vibrations the violin, which would be more free the two tables were flat, like those of guitar, and if their outline were u interrupted.

Cheap violins.

227. With a simpler construction an tolerable mechanic may mak of fine deal a good violin violoncello for a few shillings.

According to Savart, 1. The *vault* form of the face and back of a violi may be dispensed with.

2. The face should be thickest in th middle and thinnest at the edges. It best made of two pieces having or edge $2\frac{1}{2}$ lines thick, and gradually tape ing to 1 line to the opposite edge. Th two thick edges should be glued t gether.

3. The sides should be straigh forming a trapezium, parallelogram,

wedge-like shape, the small end terminating in the neck or handle.

§ 2. *Stringed Instruments struck by the Fingers.*

228. One of the best as well as most ancient of musical instruments is the HARP. It was known to the Egyptians, and frequent mention is made of it in sacred Scripture. It was a great favourite with the ancient Irish, Scotch, and Welsh, figures conspicuously in the national arms of Ireland, and, if we may believe Galileo, is of Irish invention. The modern harp is in the form of a triangle with three unequal sides. It contains from 35 to 42 parallel strings tuned in semitonic intervals, and is played by the thumb and fingers of both hands. The lowest note is generally E E, two octaves below what is termed "middle E." The strings are all of catgut, attached to a curve called the *arc-boutant*, and stretched by iron pegs inserted in the key-board.

The C-strings are coloured *red*, the F-strings *blue*, and the rest *white*. Those nearest the upright column are the thickest and longest, the first 6 or 8 being coiled with copper wire to increase their weight; the rest decrease gradually in thickness and length as they represent the higher notes. The command of this delightful instrument is greatly increased by the addition of pedals moved by the foot of the performer. By this contrivance *three several notes* can be elicited from any one string. No instrument has received greater or more valuable improvements from the industry and ingenuity of modern artists than the harp. In its present state, it is not only a model of elegance, but is also capable of "discoursing most excellent music." It is, however, far better adapted to the touch of a lady in the drawing-room than to the public orchestra.

229. Music for the harp, like that for the pianoforte, is written in two

parts, the G clef being used for the treble, and that of F for the bass. Music for the harp.

230. The GUITAR, an instrument invented by the Moors, has *six strings*, three (E, A, D) of silk covered with silver wire, and three (G, B, E) of catgut. Guitar. The interval (B G) between the second and third strings is a *third;* the other four intervals are all *fourths.* The finger-board is divided into 17 frets, disposed by semitones at regular intervals. The capacity of the instrument is nearly *three octaves.* It has very little power of sound, but is not to be despised when a skilful hand executes on it a cavatina*, ballad, or serenade.† The guitar is best employed as an accompaniment to the voice; and, as its *forte* is in chords, it is ill-adapted to solos.

* A *cavatina* is a short air without a second part; it is sometimes relieved by recitative.

† A *serenade* is a ditty performed at night under the window of one's ladye-love.

231. The strings of a guitar, like those of a harp, are struck by the fingers; the sounds thus produced are reinforced by resonance, as well as by the simultaneous vibrations of the wood-work, and of the air contained in the body of the instrument.

Played by fingers.

232. The face or sounding-board of a guitar is always made of some *soft white wood*, in order to secure in this part of the instrument the greatest possible amount of vibration. It is pierced in the middle with a round hole, called a rose, to let out the vibrations of the air contained in the box. The bands and lower table are made of maple, beech, or some other fine-grained wood.

Construction of guitars.

§ 3. *Stringed Instruments struck by Hammers.*

233. The only instrument of this class deserving notice is the PIANOFORTE, invented by J. C.

Piano.

Schröder, of Dresden, in 1717, and introduced into England by Zumpie, a German tradesman, in 1766. Within the present century it has received so many valuable improvements that it may now be ranked amongst the noblest and most elegant instruments in the whole compass of musical practice. The pianoforte is peculiarly a lady's instrument. Always graceful, it is a suitable ornament to the drawing-room. Always sociable, it is the solace of the domestic hearth. Peculiarly sweet, it is always pleasing. Sufficiently easy of execution, it is always popular; so that scarcely a house of ordinary respectability can be found without a piano, and scarcely a lady of moderate education who cannot touch it at least with tolerable skill. Many is the hour it beguiles which would be otherwise full of *ennui;* many a re-union it enlivens when conversation begins to flag; and many a winter's evening it has cheered,

and many a jaded spirit it has exhilarated. It might almost be called the good Genius of women, for never invention afforded them more innocent amusement, more accessible diversion, and more agreeable relief. There is something truly poetical in ivory keys touched into harmony by the light fingers of a graceful and elegant woman. There is something irresistibly bewitching when that harmony is accompanied by a gentle voice. In the hands of a professor the piano can pathetically complain, or elegantly trifle, or repeat the simple melodies called national airs; it can at times startle the ear with its brilliancy, move the heart with its boldness, and even verge upon grandeur and sublimity; but how exquisite soever may be the skill of a professor, the piano is infinitely more attractive at home under the touch of a friend or relation, than in the hot and gaudy concert-room, for which it is but ill-adapted.

234. The strings of a pianoforte are struck by little hammers so arranged that when the performer strikes a key, its hammer strikes the corresponding wires, and causes them to vibrate. The air resting on these strings, being thrown into sonorous vibrations by the shock, beats against the sounding-board and "belly*" of the instrument, inducing similar vibrations, which are ultimately imparted to the external air.

Piano sounded by hammers.

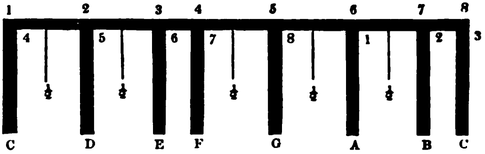
235. The different strings of a pianoforte vary in length, weight, and tension, the treble strings being the shortest and lightest, and the deep bass strings being covered with copper wire to increase their weight; but as the pitch of a string may be made obedient to its tension, the length and weight are generally regulated by conve-

* The "belly" of a pianoforte is that smooth thin board over which the strings are distended, and which, by its vibrations, greatly contributes to the tone of the instrument.

nience rather than by mathematical precision.

236. The general compass of a modern piano is a diatonic scale* of $6\frac{3}{4}$ octaves,

* Diatonic scale means a scale which proceeds by a succession of tones, as in the scale C, D, E, F, G, A, B. Though the interval between E and F is in reality only a semitone, yet it is customary to reckon it an entire interval for the sake of simplicity. The intervals of the diatonic scale may be better understood by inspecting the figure subjoined, in which it will be seen that the space between E and F, like that between B and C, is only *half* the size of all the other intervals.



It is not essential that every piece of music begin on C; but it is absolutely essential that the intervals between 3 and 4, 7 and 8, should preserve the same relative proportion. Thus, suppose a scale to begin on G, then the interval between E and F will no longer be the 3rd and 4th from the key-note, but the 6th and 7th; consequently something must be done to make this interval larger. This is accomplished by raising F to F♯, by which means a whole tone will then

beginning two octaves below gamut C in the bass; but Sebastian Erard has manufactured pianofortes which contain *seven complete octaves.*

Sounding-board.

237. The SOUNDING-BOARD should be made of some light pale wood. The slit cut along it in the shape of a fanciful curve, as well as the two carved openings covered with silk in the front board, are designed to allow the air in the case to play more freely on the external air; so that the wooden lining called the belly,

exist between E and F. The other semitone, from B to C, may remain, being between the 3rd and 4th seats. Again, the interval between the 7th and 8th notes should be only a semitone, whereas from F to G is a full tone; but as F has been raised to F♯, this interval has been rectified, and the scale is correct. This explains why *sharps and flats* are introduced into different scales. It is in order that the intervals between the notes may uniformly preserve the same formula as that given in the diagram, which represents the key of C.

In order to obtain the formula of the *minor* scale, the same diagram may be taken, commencing from A instead of C. The first semitone will thus occur between the 2nd and 3rd notes, and the second semitone between the 5th and 6th.

the sounding-board, and the vast body of air enclosed, all vibrate in unison with the strings, and contribute to augment the force of the sound.

Dampers.

238. As musical strings continue to vibrate some instants after they have been struck, and the sound of a previous note mixing with a subsequent one would often produce a discordant combination, small levers, called *dampers*, capped with cloth, are so disposed against the several wires that when a key is struck the corresponding damper is drawn away from the strings it controls, to give them room to vibrate; but no sooner is the finger removed from the ivory key, than the damper falls back upon the wires and stops their further vibration.

Soft pedal.

239. Some pianos have TWO PEDALS, one to *damp* the sound, and the other to *intense* it. When a piano has but one, it is always the forté pedal. The usual action of the "soft pedal" is to shift the hammers

sideways, so that they strike only *one* string instead of two, or two strings instead of three for each note.*

240. The action of the "forté pedal" is to lift the *dampers off the strings*, so that each set of strings may have a *larger field of vibration*, and that all the strings together may contribute to swell the force of the note struck by reciprocal vibrations. Immediately the foot is removed, the hammers and dampers return to their original position, and the effect of the pedal ceases. Forté pedal.

Reciprocal vibrations are either those produced in one musical instrument by sounding another near it, or those produced on different strings of the same instrument by the vibrations of only one of their number. The harmonics of the Eolian harp are of this nature, being produced by the communication of motion from one string to another through the medium of inter-

* Grand pianos have *three* strings to each note; others have rarely more than two. I have, however, seen pianos of French manufacture with three strings to the high treble notes, and two to all the others.

vening air. In *unisons* the sound of reciprocal tones is far louder than in the harmonics.

When a string of a violin or harp is sounded, it makes to vibrate not only all the other strings of the same instrument, but all the strings of all the instruments in the entire orchestra. Those of the same pitch vibrate in *unison*, the others contribute some *harmonic* of the note struck.

Even the string over which a fiddle-bow is drawn renders not only the very note struck, but certain others which blend with it. Thus a fundamental note elicits also the *third* and *fifth*, or the 12th and 17th, whereas an harmonic calls the fundamental into reciprocal vibrations.

SEC. II. INSTRUMENTS WITH METALLIC TONGUES.

241. Stretched strings are fixed rigidly at *both* extremities; but quills, reeds, and vibrating tongues at *one* end only.

Canon of metallic tongues.

242. When strings are fixed at *both* ends, the octave of any given note may be elicited by *halving* the length of the string. Thus, if a cord of 2 feet produce C_2, a similar cord of 1 foot would render C_3, while

another 4 feet long would give C_1, the relation between the pitch of different notes, and the length of their respective strings, being in simple inverse proportion (160.). This rule does not apply to reeds, quills, rods, and metallic tongues, fixed at one end and free at the other. In this latter case, the pitch is no longer in inverse proportion to the different lengths of the vibrating slips, but to the *square* of their respective lengths. Thus, if a steel tongue 4 inches long give C_1, a similar slip 2 inches long would not give C_2, but C_4, and another $\frac{1}{2}$ an inch long would not render C_3, but C_9; whence it may be inferred that tongues of the same weight, from which different notes are required, approach each other in length much nearer than stretched strings.

243. By soldering a small piece of metal on the under surface of those tongues which represent the lower

notes, the slips of an entire gamut may be brought to form either a continuous line, or, what is more usual in practice, a uniform gradation of lengths.

244. This will account for the *diminutive size* of this class of musical instruments; for as all the narrow slips of steel are nearly of a length, the manufacturer can enclose in the compass of a snuff-box a number of steel tongues sufficient to play any tune of ordinary limits.

245. The MUSICAL SNUFF-BOX consists principally of a cylinder or barrel full of little brass pegs. When the barrel revolves, these pegs, striking against the edge of certain narrow slips of elastic steel rigidly fixed at the contrary extremity, *bend them upwards*. As soon as the pegs have left their hold, the tongues rebound, and commence a series of vibrations. The pegs are so arranged in the barrel that, by touching the proper tongue, any note may be pro-

Musical snuff-box.

duced according to the progress of the appointed tune.

246. As these instruments are extremely small, it is customary to place them on a *table or box* in order to secure a large vibrating surface, and as much resonance as possible. The box or table, in this case, may be compared to a drum tuned in unison, and sounded by the shock of the sonorous vibrations instead of by a drum-stick. The *harmonium* is a gigantic musical snuff-box played by a key-board.

Musical snuff-box set on a table.

247. The JEWS' HARP furnishes another example of the same sort. This instrument is placed between the teeth and lips; the steel tongue is then struck by the forefinger, while a current of breath is directed between the two prongs.

Jews' harp.

248. The different notes are produced by varying the supply of breath, and by an adjustment

Notes on a Jews' harp.

of the lips. The Jews' harp, somewhat unjustly despised, is of a complex character, being partly a vibrating rod, partly a wind instrument, and in part a labial whistle or vocal hum. The performer hums or whistles the tune inaudibly between the prongs of the harp, the steel tongue enunciates the musical whisper, and the sound is augmented by resonance proceeding from the cavity between the tongue of the player and the palate of his mouth.

Repeaters.

249. The watch, called a REPEATER, invented by William Barlowe in 1676, is not strictly speaking a musical instrument, but being of a similar character to the two mentioned above may claim a passing notice. The striking apparatus consists of two pieces of elastic steel, bent into a circular form, rigidly fixed at one extremity, and struck at the other by the compression of the spring.

SEC. III. INSTRUMENTS OF PERCUSSION.

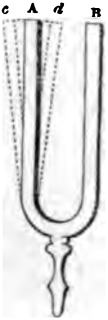
250. Instruments of percussion occupy a place between stringed and wind instruments. Their musical sounds are not due to vibrating strings or tongues, fixed in a case or frame, like the harp, violin, piano, and musical snuff-box; nor yet to the vibrations of a column of air independent of the instrument enclosing it, as the flute, clarinet, trumpet, and organ; but to vibrations made in the very substance of the instrument, and communicated by it directly to the adjacent air.

251. Instruments of percussion may be subdivided into two classes: 1st. Those which *ring*, as tuning-forks, bells, musical glasses, triangles, cymbals, gongs, &c.; and, 2ndly, those furnished with *elastic membranes*, as drums and tambourines.

§ 1. *Instruments which ring.*

Tuning-fork.

252. We begin with the TUNING-FORK. When the point A of a tuning-fork has been struck against some hard substance, it is bent inwards, and made to approach the opposite limb, as at *d*; being very elastic it rebounds and flies off in an opposite direction *c*; again it sways forwards, and again recedes with great velocity, till the instrument "is spent."



How it creates sound.

253. During the process just described several physical disturbances are created. In the first place: when the prong approaches the opposite branch, the air between the two is squeezed or condensed, and forms the nucleus of a series of condensations diverging in every direction from the centre of disturbance. In the mean time the prong recedes,

the condensed air dilates in order to fill the hiatus, and thus establishes in the opposite direction a counter series of rarefactions. The two systems form those rapidly advancing and retreating ripples of the air called sound-waves.

254. The sound thus created is augmented by the *opposite branch* B. For as the condensed air presses against its interior surface, it pushes the prong back and sets it in motion; after which the two poles of the fork vibrate in unison.

255. The force of the sound is still further increased by the simultaneous motion of the *outer* rims of the two prongs, which alternately leave behind and push back the air in contact with them. As these new sound-waves are isochronous with the former series, they become incorporated with them, and merely serve to increase their intensity.

256. After a tuning-fork has been

Tuning-fork applied to a table.

excited it is customary to apply the point of the handle to the back of a violin, the top of a table, or to some convenient surface* to render its tone more audible. For as it has no case or sounding-board of its own, the shocks which the air receives from it are limited to the narrow rims of the two branches; as soon, however, as the handle touches some extensive elastic surface, as a table-slab, and communicates to it corresponding vibrations, it secures a very powerful auxiliary, by means of which the force of the sound is considerably augmented.

French method of exciting the tuning-fork.

257. The method of exciting tuning-forks in France is very preferable to that observed in England. The two branches of a French tuning-fork are made to incline inwards towards the top, somewhat like a horse-shoe. A plug or small cylinder is inserted near the

* Technically called the *table of harmony*.

crotch or widest part, and the fork is sounded by drawing the plug adroitly, with a jerk, upwards, till it clears the instrument. By this means *both* prongs are forced back at the same time, and oscillate together; the sound is, consequently, much louder, and is free from that tinkling which results from percussion.

258. When tuning-forks are too *sharp*, the *thickness* of the branches must be reduced, to render them less elastic. When they are too *flat*, they may be made sharper by *shortening the prongs*. A very slight alteration will suffice, inasmuch as the pitch is not inversely as the length of the vibrating part, but as the *square* of that length (242.).

Tuning-forks tuned.

259 The invention of BELLS is involved in considerable obscurity. The ancient Egyptians seem to have made use of them to call the people to sacrifice. The Chinese affirm they were known in their country in

Invention of bells.

the time of Hoang-Ti, some 2600 years before the Christian era. They were used in ancient Greece in the religious ceremonies of Cybĕlé; in Carĭa, to announce the "sale of fish"; and in Rome, to call attention to eclipses of the sun and moon. In regard to their introduction into modern churches, Paulīnus, bishop of Nola in Campagna, was the first to employ them in calling the "faithful" to prayers, A. D. 400. The first ever cast in England were in the reign of Edmund I.; and his successor, in 960, caused the first tuneable set to be hung in the Abbey of Croyland*, in Lincolnshire.

260. The production of sound by means of a BELL has been described already (20.). The pitch and quality of tone in these instruments depend upon their shape, thick-

Bell.

* The largest bell in England is the *Great Tom* of Oxford, which weighs 17,000 lbs. The largest in the world is the bell of the Kremlin, which weighs 443,772 lbs., and is worth above 67,000*l.* sterling.

ness, size, the admixture of metal which enters into their composition, the manner of exciting them, and the force of the blow administered.

261. If the *lip* of a bell be made to *curve outwards* with a considerable sweep, the note will be *deeper* than when the mouth is less capacious; because a large segment vibrates more slowly than one of smaller dimensions. Mouth of the bell.

262. A bell with *thin* walls is deeper toned than one of equal size whose walls are thicker; because thin walls are more pliant, and less impatient to return to their state of repose. Thickness of bells.

263. A *large* bell renders a graver note than a smaller one; because the two axes of the ellipse alternate more slowly (*p.* 12. *note*). Large bells deep toned.

264. Lastly, the more elastic the metal of which a bell is cast the *higher* will be its tone, the louder its sound, and the longer will its vibrations be sustained.

265. The peculiarly harsh, disagreeable noise of a CRACKED BELL arises from the want of uniformity and unison in its vibrations. The continuity of the walls being broken, each separate part throws off from its surface independent sound-waves. One series issues from the part opposite to the crack, another from the part contiguous to the crack, a third from the parts between these two extremes, and a fourth from the fissure itself. This medley of sounds jostling against the drum of the ear distresses it with their confusion, and produces a sensation harsh and disagreeable.

Cracked bells.

266. After the explanations already given little need be added to render intelligible the *rationale* of MUSICAL GLASSES. This instrument was invented by Dr. Franklin of America (113. *note*), who gave it the name of *harmonica*, because he thought its tones peculiarly harmonious. Under the hands of a skilful player, it certainly

Musical glasses.

has a wonderful sweetness, extraordinary purity, and truly dramatic effect. The force of the *crescendo* and the attenuation of the notes is almost unparalleled; while the tripping delicacy of the "runs" is equalled only by the musical snuff-box.

267. Though the harmonica is excited by *friction*, yet is it essentially an instrument of *percussion*, like a bell; inasmuch as the action of rubbing is in reality a series of rapid and minute blows, which in the aggregate become sufficiently powerful to develope sound, and even heat. Manner of exciting musical glasses.

268. The usual method of *exciting* musical glasses is to rub their rims lightly with the middle or long finger, wetted with water impregnated with acid or alum. When the *right* hand is used, care should be taken to go *up* the left side and down the right; the reverse direction being observed whenever the *left* hand is employed.

269. The friction of the finger

against the edge of the glass drives *outwards* the part touched. The disturbance being communicated to the adjacent parts forces the circle into an elliptical form. A reaction takes place almost immediately, in consequence of the great elasticity of the glass, and the axes of the ellipse are reversed (20. *note*). By this shortening and lengthening of the transverse diameters, the ambient air is alternately condensed and rarefied with sufficient rapidity and regularity to produce musical sounds.

270. A set of musical glasses of considerable power and sweetness may be arranged at very slight expense, by purchasing at a warehouse some twelve or fifteen glasses of different size and note. The selection may be made from finger-glasses, beakers, soda-water and wine-glasses. In order to bring all their rims to a common level, the shorter ones can be mounted on wooden pedestals. If a deeper or flatter note be required from

Cheap harmonica.

any glass, a little water, either acidulated or impregnated with alum, will serve to depress it to the proper pitch. This homely harmonica, after a few hours' practice, may easily be made obedient to the touch and fancy.

271. Any one who can play the flute may with ease select glasses to compose a perfect scale; for by blowing strongly on the flute any given note, every glass in the warehouse of the same pitch will ring in unison.

One of the *harmonics*, as, for example, a third or fifth, will also cause the fundamental note to vibrate, and *vice versâ;* but in this case the sympathetic sound will be very feeble, whereas in *unisons* it will be full and decided (240. *note*).

272. Those who find any difficulty in making the glasses speak should first sponge their edges to remove the dust and grease; then wash their hands in warm water to soften the skin; and, having wiped them dry, dip the finger to be employed in cold water impregnated with acid or alum.

273. TRIANGLES and CYMBALS are instruments of percussion. The former instrument consists of a triangular rod of steel open at the apex and struck with a small hammer of the same metal. Cymbals are made of two metallic plates, about a foot in diameter, which are clashed together to mark the rhythm or measure of military music, dances, and overtures. In both these instruments the percussion induces in the metal a tremulous motion, which is communicated to the adjacent air.

Gong.

274. GONGS are commonly used in China, sometimes for the same purposes as bells in Europe, and sometimes for the sake of adding to the clangour of martial music. They resemble in shape a tambourine, but are made entirely of a mixture of copper and tin.

275. A gong is excited by striking the head with a mallet or kind of drumstick covered with leather. The sound *is brought* to its full force very gradu-

ally. The first blow produces only a deep bass note; but by timing the strokes skilfully, the tone rises, and ultimately acquires an intensity sufficient to make the very earth tremble. The noise and uproar of a Chinese village on a festive day, when gongs are sounding in every direction, are such as to astonish and bewilder any foreigner who may chance to be present.*

276. The sonorous power of the gong depends on the reciprocal penetration of the substances which compose the instrument; the mean density of the two metals having been considerably augmented by their admixture.

Gong metal consists of 5 parts of copper and 1 part of tin. The specific density of Chinese copper is 9000, and of tin 7299; whereas the mean density of the two together is about 8900.

* As the Chinese employ the gong, the Romans used to employ the cymbals. No religious procession, no village fête, no marriage festival was carried on at ancient Rome in which the clangour of these instruments was not introduced. Hence Ovid designates cymbals by the epithet *genialia*.

§ 2. *Instruments furnished with elastic Membranes.*

Drums. 277. The most important of this class are DRUMS, which are of three kinds: 1. the military or side drum*; 2. the Turkish or bass drum; and, 3., the kettle-drum.

278. The two former are hollow cylinders of brass, oak, or walnut wood, covered at the two ends with vellum so held at the rim as to be stretched or released at pleasure by means of small cords or braces acted on by sliding knots of leather. A small hole is pierced in the middle of the cylinder, to give passage to the vibrating air. Double or kettle-drums are generally played in pairs, and are tuned to the tonic and dominant of the piece performed. In appearance they resemble a kitchen copper, the lid or covering being of vellum or goat-skin,

* So called because it is hung at the *side* of the drummer when it is beaten.

held down by an iron hoop, and tightened or relaxed by screws fixed at the side. Such, at least, was the custom till Mr. Cornelius Ward patented his *lever movement*, by which method the tone of a kettle-drum may be altered so rapidly that any simple tune may be played on it in ordinary time.

279. When cylindrical drums are required to sound in chords to each other, as C, E, G, C_2, their lengths must be in the proportions of 4, 5, 6, 8.

280. Drums, like triangles and cymbals, are employed to mark the rhythm or measure of military and orchestral music. The parchment head is struck either with two sticks or by a single one; the part struck is forced inwards by the blow, but, being elastic, rebounds and takes up a vibratory motion.

281. The membrane in its oscillations becomes alternately tighter and more loose; by one action it *draws in* the cylinder, and by the other *lets it go*,

causing it to vibrate. In the meantime, the air both within and without is impressed by the impulses of these movements. Hence, the parchment heads, the oscillating cylinder, and the air within and without the drum are all "exciting causes" of sound; but the chief body of tone proceeds doubtlessly from the resonance of the cylinder.*

282. The *pitch* of a drum is elevated by increasing the tension of the vellum, because by this means its elasticity is augmented; but, after a certain limit, stretching the drum-head greatly enfeebles the force of sound. For when the vellum is extremely tight, its vibrations are so small that the shock given by them to the air is wholly insignificant.

283. When the parchment head is

* The largest drum in the world is at Pekin, the capital of China; it is thirteen feet in diameter. At each of the divisions of the night a sentinel strikes upon this enormous drum, and is answered at the other extremity of the city by a "ring" of bells.

damp its elasticity is injured, and the tone of the drum becomes more flat.

284. TAMBOURINES are instruments of a similar character to drums. They consist of a piece of parchment stretched over the top of a broad hoop of walnut-wood, furnished with "gingles" or bells.

Tambourines.

285. The tambourine is sounded either by sliding the finger along the parchment, or by striking it with the knuckles, fist, elbow, knee, head, or foot. This instrument, called in Scripture "a tinkling cymbal" (1 *Cor.* xiii. 1.), was a great favourite with the Jews, and is still much admired by the Biscayans, and by the coloured population of North America.

CHAPTER VI.—PART II.

WIND INSTRUMENTS.

Sec. I.—Breath instruments.

§ 1.—With a simple mouth-hole, and open at one end only.

Ex.—Pan-pipe, box-key.

§ 2.—Those in which the wind enters at one end, and comes out at the other.

Ex.—Flutes, fifes, &c.

§ 3. — Breath instruments with a beak and mouth.

Ex.—Flageolet.

Sec. II.—Reed instruments.

Cry of papers, leaves of plants, bird-calls, music of straws, leeks, nettles, and bulrushes.

§ 1.—Reed instruments with *one* flexible reed.

Ex.—Clarinet.

§ 2.—With two flexible reeds.

Ex.—Hautboy, bassoon.

Sec. III.—Musical instruments with a cup mouth-piece.

§ 1.—Those without keys.

Ex.—Trumpet, trombone, horn, &c.

Sec. IV.—Whistles and whistling.

Ex.—Bird-call, dog-call, peach-stone, elder wood, hazel-nut, whistling of wind among rocks, through fissures and key-holes, lip-whistle, whistling through the teeth, through the fingers, by the fist.

Sec. V.—Instruments with bellows.
§ 1.—Organ mouth-pipes.
§ 2.—Organ reed-pipes.
§ 3.—Promiscuous remarks on the organ.
§ 4.—Miscellaneous instruments with bellows.
Ex.—Barrel-organ, orchestrina or harmonicon, harmoniphon, harmonicum, eolophon, seraphin, accordion, concertina, and bag-pipe.

286. Wind Instruments differ essentially from those already described. They contain no vibrating strings, nor steel tongues, nor stretched parchment. Neither is the *substance* of the instrument the sonorous body, as is the case with bells and cymbals; but the *air* contained in the tube, set in motion by the breath or by a pair of bellows.

287. That the *air* is in reality the sounding body in these instruments, and not the walls which confine it, will appear evident from the following considerations: 1st. *The sound is not arrested by a touch.* If a finger be laid upon a bell, triangle, or drum-head, the sound is instantly silenced, because the weight of the touch arrests the vibra-

tions; but the two hands of a flutist, the pressure of the entire grasp of a trumpeter, and even the additional weight of the arm in certain wind-instruments, do not in the least impede their sound, or even affect its quality and pitch. 2ndly. The sound of all "ringing" instruments is materially influenced by the *thickness and nature of the material which constitutes them.* A thick bell gives a higher note than a thin one; a silver bell renders a note of different pitch to a brass one, and this latter to one of bell-metal. This is not the case with *flutes.* It is a matter almost of indifference, so far as pitch is concerned, whether the tube of a flute be thick or thin, whether it be made of paper or wood, of ivory, glass, or silver. So long as the instrument retains the same length, size, and shape, it will invariably render the same note. Without doubt the *quality* of that note will be affected by the material: in one case it will be more

sweet, more rich, mellow, and agreeable, in another more meagre, harsh, and displeasing; but the *pitch*, that is, the exact gravity and acuteness of the instrument, is entirely independent of such circumstances.*

288. The reason why the *quality* of the note is affected, and not the pitch, is because the former is due to the vibrations of *resonance*, that is, vibrations emanating from the material of the instrument; whereas "pitch" depends solely on the vibratory motions of the column of air, independent of the tube which confines it.

289. Wind-instruments may be divided into two grand classes: 1st. Breath instruments; and 2ndly. Bellows instruments. The former of which must be subdivided into four species, according to their respective embouchures or mouth-holes: (1), those with a simple orifice or bore, as

Different species.

* If the walls of a wind instrument be very thin indeed, the pitch is depressed a trifle.

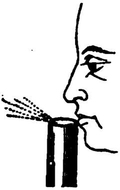
the pan-pipe and flute; (2), those with a beak and mouth, as the flageolet; (3), reed instruments; and (4), those with a cup-like mouth-piece, as the trumpet. Some of these will require still further sub-division.

SEC. I. BREATH INSTRUMENTS.

§ 1. *Those with a simple Mouth-hole, and open at one End only.*

290. Of instruments with a simple mouth-hole, and open at *one* end only, the most important is the PAN-PIPE *, sometimes called the *Mouth-organ.*

* In Greek mythology it is said that Syrinx, an Arcadian nymph, inspired by the love of Pan, went one day alone to the mountains of Lycæus to meet the rustic god. Pan, however, shocked the maiden by his rude behaviour. She fled to Ladon, her river-father, and requested to be changed into a reed. The god was not to be thus foiled; for he instantly plucked the reed, and made of it a musical instrument. This pretty fable is merely an ingenious way of saying that the shepherd Pan remarked that a reed agitated by wind rendered a melodious sound, and consequently plucked one from the banks of the Ladon, to make of it a pipe.



291. In order to make a box-key or a pan-pipe speak, the performer must blow *across* the orifice, and not directly *into* it. By this means the breath is split against the opposite edge; a part flies off exteriorly, and a part rebounding falls into the tube. The two parts by their respective impulsions condense the air against which they beat, and establish two series of vibrations, one *outside* and one *inside* the pipe. These do not in every instance exactly coincide, but the former is at least an harmonic of the latter, and immediately the vibrating air quits the tube, it takes up the harmonic and assimilates it to fortify its own note.

How sound is produced in pan-pipes.

292. In these instruments the sound is created by the impulsion of the breath against the edge of the orifice. The column of air confined in the tube is not, strictly speaking, the *sounding* body, but only

an auxiliary which serves to amalgamate the *resonance* proceeding from the sides of the tube with the sonorous vibrations circulating through it. The sonorous body is that portion of the *breath which strikes against the sharp edge of the embouchure.*

As soon as the breath enters the pipe, it condenses the air upon which it falls; a series of condensations begins from this point, reaches the bottom of the tube, is reflected back again, and makes its way into the open air. In the mean time, each condensed portion *dilates*, giving that tidal motion to the air always essential to the production of sound.

Fundamental sound and its harmonics.

293. Each reed of a pan-pipe has a note more easily elicited than any other; this is called its fundamental sound, and is always the *deepest* which can be produced. By increasing the force of the breath several other notes may be elicited, which are called harmonics.

Stainer p. 13

Harmonics of a pan-pipe.

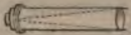
294. Suppose the fundamental note of a reed closed at one end to be C, its harmonics are (1), the double fifth G_1; (2), the major third of the double octave E_2; and (3), the flat seventh of the same octave $B\flat_2$ or $A\sharp_2$. The following notes may also be obtained from the same pipe by skilful management of the breath and lips: D_3, $F\sharp_3$, $A\flat_3$, B_3, &c. So that a pan-pipe with seven reeds has seven fundamental notes, and a considerable number of harmonics.

On all wind and keyed instruments, including the organ and piano-forte, the following sharps and flats are identical: viz. C♯ and D♭, D♯ and E♭, F♯ and G♭, G♯ and A♭, A♯ and B♭. On the violin, violoncello, &c., and on the trombone a slight difference exists between these respective notes.

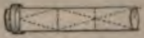
Nodal points.

295. The reason why several notes can be drawn from the same reed is this: When a person blows into it gently, the column of air contained in the tube divides itself into "half a loop," the knot being at

the bottom, and the greatest swell at the orifice, thus:



But when the breath is somewhat forced, the condensations and rarefactions succeed each other more rapidly, and a higher note is produced. As the vibrations are more *rapid*, their ~~amplitude~~ is smaller (*Chap.* V. *sec.* iv.), and the column divides itself into three equal parts, still preserving a knot at the bottom and a swell at the orifice, thus:



an arrangement similar to the former *thrice* repeated.

If the breath be still further enforced, the column of air will be divided into *five* equal portions, then into *seven*, then into *nine*. Whence it will be seen that the nodal divisions of a tube *closed at one end*, follow the unequal series 1, 3, 5, 7, 9, &c.

296. By referring to the table given under No. 182., it will be seen that C gives 256 vibrations in a second; this is the note we have supposed to be the *fundamental* one of the given reed (294.). Harmonics explained. As in the second instance the reed is divided into *three* equal parts, to find this harmonic we must search for a note which vibrates *thrice as fast* as the former: this note will be G of the next octave, which gives 768 vibrations while C makes 256. For the second harmonic the pipe is divided into *five* equal parts; the note produced, therefore, must vibrate *five times* as fast as the fundamental; this by the table will be found to be E of the third octave, which gives 1280 vibrations while C makes 256. The next harmonic is procured when the column of air divides itself into *seven* equal portions; this note, therefore, vibrates *seven times* as fast as the fundamental. Now $256 \times 7 = 1792$, and the nearest

number we find in the table is A_2, which gives 1706; the vibrations of this note are consequently too slow, and the harmonic in question is $A\sharp_2$ or $B\flat_2$, a note which lies between A_2 and B_2.

§ 2. *Breath Instruments with a simple Mouth-hole, in which the Wind enters at one End and comes out at the other.*

297. The musical instruments which belong to this category are FLUTES, THIRDS, OCTAVES, and FIFES.

In all these instruments the breath enters a little obliquely through a mouth-hole in the *head* of the tube, and makes its way out through the other extremity, called the *foot.* Poets attribute the invention of the flute to Apollo, Mercury, and Pallas; Pan is fabulously considered to have been the father of the flute with seven unequal reeds (B.C. 1770); Marsўas, the mythological shepherd of Phrygia, the

inventor of the *double flute* (B. C. 1375); and Hyagnis, the father of Marsўas, to have been the first to play on a *single pipe furnished with stops*. The flute now used in orchestras and concert-rooms is about 18 inches long, 1 inch in diameter, consists of several joints which fit into each other, has 6 finger-holes, and a varying number of metal keys. Of all wind-instruments, the flute takes the highest range. Its tones combine the reedy quality of the hautboy with the rich mellowness of the clarinet.

298. The great defect of a flute is the faultiness of some of its notes. For example: without keys expressly for the purpose, it is extremely difficult to sound exactly in tune either F natural or F sharp; the former is as much too sharp as the latter is too flat. The same remark applies to some other notes, especially in the third octave, which is always fatiguing to sustain. Another defect

Defects of the flute.

is the difficulty of keeping the flute in tune with other instruments, because the humidity and heat of the breath swells the tube, increases its elasticity, dilates the vibrating column, and renders the flute altogether too sharp; in consequence of which, it needs always be used some little time before it joins in concert with other instruments.

How to blow a flute

299. The mouth-hole of a flute is applied to the centre of the upper part of the under lip, so that the lip covers at least half the hole. The breath is then forced through a small aperture of the lips, strikes against the sharp edge of the embouchure, is lacerated by the percussion, and a part flies into the cylinder while the rest bounds off exteriorly. The two portions create sound-waves by condensing the air with which they come in contact, and the two sounds coalesce to form one note immediately the vibrating column reaches the foot of the instrument.

Flutes with beaks.

300. Flutes are sometimes furnished with a beak, fastened by means of a spring over the mouth-hole in such a manner that the stream of breath may fall upon the sharp edge of the embouchure without spreading over the sides of the flute,—a fault by no means unusual, but which always produces a disagreeable hissing or whistling noise.

Wetting the lips.

301. The same sort of whizzing is heard when the lips of the flutist are very moist; hence the habit of touching them continually with the tongue in playing is greatly to be deprecated, as it causes both waste of wind and loss of tone.

Nicholson's instructions.

302. The late Mr. Nicholson, in his book of instructions for the flute, says that the breath should be forced *vertically* into the flute without *touching the edge of the mouth-hole* at all. If this direction were followed literally, the flute could not be made to speak. Let any one hold the palm

of his hand near the mouth-hole of a flute when a note is sounded, and he will feel the lacerated breath bounding from the edge of the embouchure. If Mr. Nicholson's notion were correct, this would never happen with a respectable player; nay, the edge of the mouth-hole might be even *rounded;* but such an arrangement would be practically as well as theoretically untenable.

303. A flute contains six ventages or finger-holes, which represent six fundamental notes; but by the play of the lips and fingers, and by the assistance of keys, it has a range of three entire octaves, with the same number of flats and sharps as a pianoforte. The scale begins from C on the first line below the treble staff, and goes to C above the fifth leger-line over the same staff.

Compass of the flute.

304. The second octave of the flute is produced by precisely the same fingering as the first, with the exception of D, for which

Second octave of the flute.

the D-key is to be held down, and the first finger to be lifted up. In this octave the pressure of the flute on the lips should be lessened, in order that the under-lip may be thickened, and the current of breath have a more elevated line to traverse before it enters the mouth-hole. As the pressure of the flute is less, both the mouth-hole and also the embouchure of the lips are somewhat enlarged, the volume of the breath increased, and a fuller resonance produced.

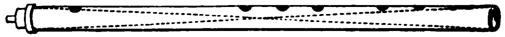
305. For the *third* octave, the under jaw must be made to project, in order to give the current of breath a still more elevated line. For G, A, B, C, the size of the mouth-hole must be reduced by turning the flute inwards and bringing the upper lip close to the hole, to prevent the spread of the breath.

Third octave of the flute.

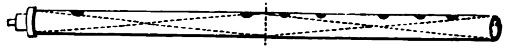
306. The fundamental note of a flute is produced when the entire column of air forms a single

Harmonics of a flute.

"node" midway between the two extremes. Thus when D, the first* note of the scale, is produced, the column of air forms a nodal point in the middle of the tube and a swell at each end, thus:



By forcing the breath a little, the player obtains the *octave* of the same note; for the column of air then forms into two arrangements like the former:



the effect in this case being the same as if *two* flutes were employed, each half the length of the one in use.

If the breath be still further enforced, the column of air will divide itself into *three*, then into *four*, then into *five*, then into *six* similar arrange-

* D is the lowest note of the scale when a flute has only one key; but with what are called "keyed flutes," C can be drawn by closing the C key.

ments; so that the harmonics of a flute follow the natural order 2, 3, 4, 5, 6, 7, &c., the fundamental note being *unity*.

307. Suppose the fundamental note to be D; by forcing the breath, the flütist obtains the *octave* D_1 for the first harmonic; then the double *fifth* A_1; then the *double octave* D_2; then the *major third* of the same octave $F\sharp_2$; and so on. The first harmonic of a flute must be the octave, because the column of air, by forcing the breath a little, divides itself into two equal parts, and the octave vibrates just *twice as fast* as the tonic. By turning to the table (182.), the other harmoncis may be readily found.

308. THIRD-FLUTES have a pitch *one-third* higher than the ordinary flute, and are one-third shorter. Third-flute. Those called OCTAVE-FLUTES are *half* the length of common flutes, and receive their name because their scale is an *octave higher*. In every instance

the different pitch of these tubes corresponds with their respective lengths.

309. This will explain why the lowest note of these instruments is produced by stopping all the ventages, because by that means the longest possible vibration is obtained.

Low D of flutes.

310. It will also explain why a flutist draws out the upper slide of his instrument when he finds it too *sharp*, and pushes it further home when the flute is *flat*. By the former arrangement he lengthens the column and depresses the pitch; by the latter he shortens the column and elevates the tone.

Tuning flutes.

311. Octave-flutes are pitched for the key of D; FIFES for E♭ and F. Octave-flutes are generally employed in concert-rooms, and fifes in military bands. Music for the flute, octave, and fife, is always written in the treble or G clef.

§ 3. *Breath Instruments with a Beak and Mouth, as the Flageolet.*

312. The *beak* of a flageolet is the tube through which the player blows; the *mouth* is a small hole just below the shoulder-piece. The lower lip of the mouth is bevelled, like the edge of a chisel, and inclines a little inwards.

313. When the player blows through the mouth-piece, his breath is split by striking against the edge of this "lip;" part of the wind flies through the hole into the air, and the rest rebounds into the instrument. The two portions create sonorous vibrations, one without, and the other within the tube. **Flageolet.**

314. The sound of a flageolet is engendered at what is called "the mouth" of the instrument, but is greatly reinforced by resonance in its passage through the tube. The *pitch* of the pipe is so **How sound is produced by flageolets.**

much more acute as "the mouth" is small, the tube short, and the blast strong.

315. A flageolet is pierced with six ventages or finger-holes, and commands a scale of about two octaves, beginning from D in the treble staff. Its music is written in the G-clef.

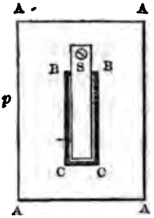
Compass of a flageolet.

SEC. II. INSTRUMENTS WITH REED-BEAKS.

316. Reed instruments, such as hautboys, bassoons, and clarinets, differ essentially from those described in the previous sections, inasmuch as the sounding body is not the breath of the performer, but the *column of air* contained in the instrument. In the former case the column of air is only the *auxiliary* of the sounding body; in the latter it is the sounding body itself.

317. The action of vibrating reeds

may be illustrated in the following manner. Let A A A A be a plate of zinc or copper, B B C C a part cut out. At the point S let a thin slip of elastic metal be soldered on the plate, and let it be free to oscillate through the aperture B B C C, without grazing the edges. If now a person apply the plate to his lip at the point *p*, and blow towards C C, the metal tongue will alternately open and shut, allowing the breath to pass intermittingly, and engendering sonorous vibrations whose length will depend on the dimensions and elasticity of the metal tongue.



318. By blowing against the edge of a PIECE OF PAPER, a sound may also be produced, because the leaf flaps against the adjacent air on both sides, communicating to it those motions of progression and regression called vibrations.

Cry of paper.

Cry of leaves.

319. Boys sometimes place the LEAF of a plant betwixt their thumbs, and produce a shrill shriek by blowing upon its upper edge. Sometimes they cut a slit in a piece of soft wood, like deal, make the two clefts of it very thin, and insert therein some half-dozen pieces of paper, the edges of which are cut close to the stick. By blowing into the slit either at the top or on one side, a loud squeaking sound resembling the cry of monkeys may be produced.

Bird-calls.

320. The cry of birds may be imitated with considerable success by inserting in a slit made in a small stick of wood the leaf of some particular plant, the choice of which must depend on the cry to be imitated. A laurel leaf is best to mimic the voice of lap-wings; ivy that of pies, blackbirds, and thrushes; a leek, the jug of nightingales; and a blade of dog-grass the hoot of owls. The dog-grass should be taken from some plantation or dry

ditch, where may be found a species without hair, very fine, and of a yellowish green colour. The other sort is so hard and thick that it would make the lips bleed unless first soaked in vinegar. Instead of a stick, some persons hold the leaf between the forefinger and thumb of each hand.

321. Sometimes a green WHEAT-STRAW is cut below a knot so as to make a tube *open at one end only*. About one-third from the open end a slit is cut in the straw, having a direction upwards. The young musician places this straw in his mouth, blows into the orifice; the slit vibrates, and a harsh scrannel "fills the air with barbarous dissonance." Cry of a wheat straw.

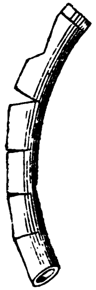
By piercing finger-holes in the straw, sounds of different pitch may be obtained.

322. The stalk of a leek is often employed for the same purpose. The stalk is merely cut some Cry of a leek.

two inches in length, and the smaller end applied to the lips.

Cry of a nettle.

323. An instrument resembling a bag-pipe in tone may be made of a NETTLE. The stalk of a white nettle should be cut off below a knot; the upper surface of the part just below this knot scraped very thin, and a small slit cut through the inner film. From this part to the bottom of the stalk, which should be without a knot, incisions should be made at equal distances nearly through the stem, and the nettle bent into the form of an arc. The knotted end is put into the mouth, when, by blowing and bending the nettle more or less, sounds by no means unmusical may be produced.



324. These illustrations will serve to explain the *modus operandi* of reed instruments, which may be classified

under two heads, those with *one* flexible reed, and those with *two*.

§ 1. *Reed Instruments with one flexible Reed, as the Clarinet.*

325. The mouth-piece of a clarinet consists of a beak, generally of ebony, box, or cocoa. About one-third of the solid wood is cut away, to give room to a flat elastic reed, which is fixed at the *bottom*, and gapes a little at the upper edge of the beak. The body of the clarinet has seven finger-holes and a number of keys, varying from six to fourteen. Clarinet.

326. When the player forces a puff of breath into this mouth-piece, the slip of reed vibrates, and communicates its motion to the air in the tube. Sound-waves are thus produced, which are reinforced by resonance in their passage through the pipe. How clarinets produce sounds.

327. Without doubt the same vibratory motion which sets in undula-

tion the column of air contained in the clarinet must also communicate a similar motion to the air in contact with the outside of the reed; but, in the former case, the confined air, being less fugacious, receives and transmits a much stronger impulse than the latter; in consequence of which the note it produces is so much more powerful that it overwhelms the other sound and incorporates it.

Character of the clarinet.

328. The clarinet was invented at Nuremberg, in Germany, about two centuries since. Gluck* was the first to introduce it into dramatic music. Though it includes every semitone within a compass of twenty-seven notes, it is virtually a very imperfect instrument, inasmuch as it changes the character and "tim-

* Gluck, generally called the Michael Angelo of music, was born of low parents, in Bohemia. His operas of *Alceste*, *Orpheus*, and *Iphigenia in Aulis*, won by their boldness and originality almost unparalleled applause. He died 1787, aged seventy-three.

bre" of its tone at each octave. The first twelve notes are clear and sweet; the next nine, sonorous and clarion-like; the rest, both shrill and disagreeable. Again, some of its tones are false; the player has not a free choice in his keys, the only ones heard to advantage being those of C and F; and the very position of the keys is such as to render certain passages and trills wholly impracticable. Yet, notwithstanding all these defects, the clarinet forms the foundation of mixed military bands, where it takes the same range as violins occupy in symphonies and dramatic music.

329. Clarinets are made of various keys; those most generally introduced into orchestras are A, B flat, and C. The B-flat clarinet is by far the best, and the A the most faulty. Solos for the clarinet are generally written in C, F, and B flat.

§ 2. *Musical Instruments with two flexible Reeds, as the Hautboy and Bassoon.*

Hautboy.

330. The HAUTBOY is a conical tube of cocoa, box, or ebony, 22 inches in length, and widening gradually from the top to the bottom. It is pierced with six finger-holes, and supplied with a variable number of keys.

Compass of the hautboy.

331. The general compass of the hautboy extends from the C clef note to D in alto; but solo performers can frequently carry it two or three notes higher. Its scale contains all the semitones except the sharp of the lowest note. Its music, like that of the Clarinet and Flute, is written in the G-clef.

Reeds of the hautboy.

332. The *mouth-piece* of the hautboy consists of two slips of reed bound together at the bottom, but free to move at the top, where they are extremely thin and

form an elliptical orifice. When the performer blows through these reeds, his breath causes them to vibrate; and their tremulous motion is communicated to the column of air contained in the instrument.

333. The tone of the hautboy, in skilful hands, is grateful and soothing. It can be martial, rustic, and even joyous, but is peculiarly adapted to the expression of soft and plaintive passages. As, however, the reeds which form the beak are exceedingly thin, and their aperture must be modified by the pressure of the lips, the instrument is difficult to play. Unskilful performers frequently provoke from it a harsh scrannel, familiarly called a *goose;* either because they force their breath too violently into the pipe, or else because the reeds are allowed to vibrate throughout their entire length. In the former case the instrument is forced beyond its natural pitch, and the *reeds* only speak; in the latter, the

Hautboy "Goose."

reeds and pipe do not *vibrate in unison*, and the sound is grating, like that of a cracked bell (242).

There is a limit of pression in all tubes, beyond which sound ceases altogether. If an unskilful player force a pipe beyond this limit it cannot speak.

The general compass of the hautboy is from C in the clef to D in alt, but solo players can carry it two or three notes higher. Its scale contains all the semitones, except the sharp of its lowest C.

Bassoon.

334. The BASSOON serves for the bass in a concert of hautboys, clarinets, and flutes. It is formed of two tubes in juxtaposition, each four feet long, communicating with each other only at the lower extremity. It has eight finger-holes and ten keys. Its compass comprehends three octaves, with every semitone from double B♭, to B above the treble staff. Its mouth-piece resembles that of the hautboy, and the rationale of its sound is precisely the same. Though the character of this instrument is tender and plaintive, its accents are full of vigour and sentiment,

serving to express tumultuous passions. It is never brilliant itself, but unites admirably with those that are so, and makes a most spirited bass when violins leave the orchestra free to the wind-instruments. It can modulate a solo with considerable grace and suavity, but its *forte* is accompaniment when it fills up the void between intermediate instruments, and suits either the rapid march of the violin or the tardy gait of the trumpet. Its tones are not always to be singled out, but, as the violet hidden among herbs is detected by its perfume, so the presence of the bassoon in a full band is rendered perceptible by the harmony it introduces.

Its best notes are C, F, B♭, E♭, and their relative minors.

The word bassoon is a corruption of the two French words *bas-sons* (deep-sounds).

SEC. III. MUSICAL INSTRUMENTS WITH A CUP MOUTH-PIECE.

335. The mouth-piece of TRUMPETS,

HORNS, and of other brass instruments consists of a small hollow hemisphere or cup, technically called in French a BOCAL.

336. In all these instruments the sound is occasioned by the shock given to the air in the mouthpiece by the breath of the performer, and is varied chiefly by varying the pressure of the lips.

How sound is produced.

337. In order to make these instruments speak, the player gives an impulse to his upper jaw with the tip of his tongue, great care being taken never to let the tongue intrude beyond the lips. The jerk thus given to the breath shocks the ear in the mouthpiece, which thence becomes the seat of sound. The intensity of the sound thus engendered is increased: (1.) By the vibrations of the instrument itself; and, (2.) by resonance in its long and tortuous passages. The "ring" of the metal walls causes the peculiar *timbre* or quality of tone which characterises a *brass band*.

There is no good reason to believe that the sound of these instruments is engendered by the ***tremulous motion of the performer's lips***, as most physiologists maintain. Every trumpeter knows that trembling lips are so undesirable, that it is customary to rub them with alum to harden them; if after this the lips quiver, the instrument must be laid on one side. That the lips ***vibrate*** may be admitted, but their vibration is the ***effect*** and not the ***cause*** of sound. When vibratory motion is communicated by the breath to the air in the mouth-piece of a horn or trumpet, the lips may probably vibrate as accessories, but certainly are not the ***primum mobile*** of the sound.

338. Instruments with a cup or hemispherical mouth-piece may be subdivided into two classes: those without keys, and those with keys or finger-stops.

§ 1. *Musical Instruments with a Cup Mouth-piece, and without Keys, as Trumpets, Trombones, Clarions, French Horns, &c.*

339. A TRUMPET consists of a folded tube, usually of brass, with a large bell-shaped mouth, called its pa- Trumpet.

vilion. It is the loudest of all portable wind-instruments, and, from its exciting effect, is admirably adapted to military music.

In an orchestra trumpets have occasionally a truly thrilling influence by their brilliant blast, and that sublime monotony which contrasts so effectively with the precipitate march and impetuosity of other instruments, adding vigour to the design of the composition, marking strongly its contour, and giving expression at a moment when other artifices are exhausted.

Trumpets are generally employed in pairs, called 1st and 2nd trumpet. They sound the tonic, subtonic, mediant, and dominant of four octaves.

340. The *conical shape* of horns and trumpets contributes greatly to the intensity of their tones, inasmuch as the sound-rays issue from the pavilion in *parallel lines*, instead of diverging on all sides.

Shape of trumpets.

341. The wide bell-like mouth of

brass instruments increases the *depth* of their tone, as it gives the effect of a larger segment, which vibrates more slowly than one of less diameter. The more the lip of a trumpet or horn is curved outwards, the greater will be the discrepancy between the tube of the instrument and its pavilion. This accounts for the extraordinary depth of tone in French Horns.

Mouth of trumpets.

Music for the trumpet is written in the G clef.

342. HORNS were originally designed for the chase; but Punto*, Duvernoy†, and Dauprat‡ have given them a new existence, and enriched

Horns.

* Jean Punto, or, more correctly speaking, Jean Stich, the celebrated cornist, was born at Zchuziez, in Bohemia, 1748, and died 1803. He used a silver horn, the tone of which he considered more pure and more brilliant than those made of brass.

† Frederick Duvernoy, or Duvernois, was born on Mount Béliard, one of the Alps, 1765, and died 1820. He was cornet in Napoleon's own band, where his talents were highly appreciated. His execution was faultless, and his tones, though limited to a very few notes, were remarkable for their purity.

‡ Professor Dauprat, celebrated both as a composer

them with a multitude of sounds which nature seems to have denied them. Though rich and sonorous, they can be tender and pathetic. They can take a solo, but are better adapted to accompaniment, in which their noble thirds and fifths are truly charming.

The pitch of a French Horn is an octave lower than that of trumpets. The lower part of its scale includes only the *third*, *fifth*, and *eighth* of the key, but in the upper octave it takes all the natural notes, and even commands the sharp *fourth*. Its *natural fourth* is, however, seldom in tune, and should always be avoided by composers.

343. Blowers of the French Horn usually place one of their hands in the pavilion of their instrument to procure certain varieties of tone called "shut notes." The hand serves to impede somewhat the vibrations of the column of air; and consequently, abases the sound.

Hand in the pavilion.

and as a cornist, was born at Paris, 1781, and died 1832. He was honorary member of Napoleon's chapel, and was afterwards appointed to the *Chapelle de Lois* by Louis XVIII.

French horns played in pairs are usually arranged to turn one to the right and the other to the left hand of the player.

344. A performer on the French Horn can elicit from his instrument *without the aid of his hand* eleven notes taken from four octaves, and *by the aid* of his hand in the pavilion eight more. The higher notes are elicited by pursing the lips, and the lower ones by relaxing them. It is rarely the case that the same cornist can render equally well both the high and low notes, because the physical condition of the lips necessary for the one is most unfavourable to the other. The notes most easy of execution on a C horn are C, E, G; on a D horn D, F, A, &c.; but it is extremely difficult to draw D, F, A from the former, or C, E, G from the latter. Semitones may also be produced when attention is especially directed to them, but in practice it is almost impossible to give a tone and semitone in succession.

345. When it is required to change

the key of a horn, the branch to which the mouth-piece is adjusted must be changed for one of a different length; by this means a C horn can be tuned to the keys of D, E♭, F, G, A, and B♭.

The notes producible on a horn *without the aid* of the hand are C_1 G_1, C_2 E_2 G_2, C_3 D_3 E_3 G_3 $B\flat_3$, C_4. The lowest note, C_1, is that of an open organ-pipe eight feet long.

By the aid of the hand in the pavilion eight other notes can be produced, A_1 B_1, D_2 F_2 A_2 B_2, F_3 B_3; but these latter, called "shut notes" are many of them difficult to execute.

Trombone.

346. A TROMBONE, anciently called a *sacbut*, consists of three tubes: the *first*, to which the mouth-piece is attached; and the *third*, which terminates in a bell-shaped aperture, placed beside it. The *middle* branch is folded, so as to slide into the other two like the tube of a telescope.

347. Gluck* was the first to introduce this instrument into orchestral music. With a mechanism remarkable for its simplicity it has the advantage

* Gluck, see p. 214.

of running through all the notes of the scale and of producing each in perfect tune by means of its sliding tube. Thirds, fifths, and octaves are obtained by the pressure of the lips without changing the position of the middle branch. The trombone has a noble effect in symphonies, overtures, marches, and indeed in all brilliant or solemn music.

348. There are three sorts of trombones used in orchestras, the alto, tenor, and bass. When employed together they form a complete harmony in themselves. Species.

An *alto* trombone contains eighteen notes, the lowest being C above G gamut;

A *tenor* trombone contains fourteen notes, the lowest of the scale being A one note above G gamut;

A *basso* trombone also contains fourteen notes, commencing one note below the tenor instrument, and reaching to C above the bass-clef note, producing every semitone within that compass.

Music for the trombone is written in the C

clef, *third* line for the alto, *fourth* for the tenor; and in the F clef for the basso.

N.B. *Brass instruments with keys or stops, such as the ophicleide, cornet-à-piston, &c., present no new physical features; and may, therefore, be passed over.*

SEC. IV. WHISTLES AND WHISTLING.

Tin bird-call. 349. The box-WHISTLE or bird-call consists of two circular plates of tin, each pierced in the centre with a small hole, and attached to a small tin band. The instrument is placed between the lips, and its cry provoked either by blowing or drawing the breath through it. The acuteness of the sound is, by increasing the force of the blast, augmented in the same ratio as in the flute (307.); and the gravity is in proportion to the size of the bores, the largest bore producing the deepest tone.

How it produces sound. 350. The breath forced into the box *drags from the cavity a small quantity of air.* Upon this, the rest of the air in the whistle dilates, in

order to occupy the void, and in its rarefied condition can no longer resist the pressure of the external air, which crowds into the whistle and causes a sudden condensation. This dilatation and compression of air in the cavity of the instrument give birth to those minute advancing and retreating movements so mysteriously connected with the phenomenon of sound. Resonance and the vibrations of the tin itself increase the force of the whistle and modify its tone.*

Peach-stone whistle.

Boys make a similar whistle by grinding a hole through the upper and under surface of the cornel of certain wall-fruit, and removing the "meat" piecemeal. A peach-stone whistle is used by fowlers to imitate the cry of larks.

Dog-call.

351. The DOG-CALL or sportsman's whistle consists of a small cylinder, generally of ivory, fitted

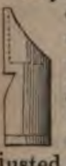
* The explanation given in the above paragraph refers to the method of *blowing through the whistle.* The intelligent reader can very easily modify it so as to make it applicable to the other means referred to.

with a beak or mouth-piece at one end and closed at the other. The shape of the beak somewhat resembles that of a clarinet, but it is furnished with a *mouth* like the flageolet (312.).

352. The sound is produced by forcing the breath against the sharp lower lip of the whistle; upon which a part of the breath flies outwards, and the rest falls into the cylinder. Both these portions compress the air against which they strike, and the condensed air, having compressed other portions, dilates, and returns to repose. As soon as the vibrations established within the whistle reach the bottom of the "call," they are reflected upwards, and make their way out through the mouth of the beak.

How it produces sound.

Boys make these whistles of elder wood by cutting obliquely the upper end of an elder-stick, and inserting therein a plug of wood so as to leave only a small orifice just below. A notch is cut with a sharp lower edge, and the bottom of the cylinder is closed with a piece of wood nicely adjusted to the size of the tube.



353. Sometimes the intensity of sound in these whistles is increased by means of a small pea shut up in the "call." The pea, which flutters in unison with the vibrating column of air, increases the shock of its vibrations. The harmonics of a dog-call are the same as those of a Pan-pipe and of all other instruments open only at one end (294.).

354. Whistling through a HAZEL-NUT is performed by blowing obliquely across the hole of a hollow nut. This phenomenon is precisely analogous to the whistle of a box-key or Pandean pipe (291.).

Hazel-nut whistle.

355. The WHISTLING of WIND among rocks and through fissures is connected with many of the superstitions of the ancient Britons. Sir Humphry Davy*, in his Salmonia,

Whistling of wind.

* Sir Humphry Davy, born at Penzance, in Cornwall, 1778, died at the age of fifty-one, A.D. 1829. He was a celebrated chemist, and is universally known as the inventor of the *safety lamp*.

says: "In the West of England, half a century ago, a particular hollow noise on the sea-coast was referred to a spirit or goblin called Bucca, and was supposed to foretell a shipwreck." Sir Humphry explains the cause of this peculiar noise in the way following: "Sound travels much faster than currents of air, and the sound referred to always precedes a heavy storm, which seldom takes place on that wild and rocky coast without a shipwreck on some part of its extensive shore."

The place referred to by Sir Humphry Davy is in Cornwall, and the hollow noise proceeds from the gullet of two rocks which stand in such a direction as to leave an opening towards the south-west, the very direction of storms in England. As these storms are sure to dash vessels against the coast of Cornwall or Devonshire, it is easy to perceive how the howling of the wind has become associated with the voice of a malignant spirit.

356. Similar noises have been observed by every one in a high wind from narrow passages, chimney-flues, and key-holes. The wind, beating in gusts into the orifice of these openings, compresses the air against which it strikes, and drives it back. The air thus dislodged condenses other contiguous portions, dilates, and returns to repose. A vibratory motion is thus imparted to the column of air contained in the flue or fissure which becomes the seat of sound, and the sound thus engendered is augmented in its progress through the tube by resonance and sometimes by accidental circumstances.

Howling of wind through key-holes.

357. The *tone* of the howl or whistle depends on the substance of the fissure walls. The *pitch* on the length, calibre, and shape of the chink or aperture.

358. A tube of convenient length, nicely adjusted to a key-hole or other

sonorous orifice, greatly increases the intensity of the sound by the concomitant vibrations of its column of air.

As a rule, the *pitch of a tube is deepened in the same proportion as its length is increased;* but this rule is subject to several limitations:

1. There is a *maximum of abasement.* If the length of the tube exceed this maximum, the tone mounts higher and higher till it attains the maximum of elevation. If after this the tube be still lengthened it gradually drops *one-fourth,* then mounts again. The next descent upon increase of length will be *one-third;* after which the tone mounts again. And so on alternately.

2. The length of a tube ought not to be more than twelve or fourteen times greater than the diameter of its bore, in order to obtain from it its fundamental or normal note. When a tube exceeds this proportion of length, the first note is *abnormal;* it may be the octave, the double-fifth, the double octave, or some other harmonic. If it be the *octave,* its pitch will not be affected even if *half the length* of the tube be cut off. If the *double-fifth, two-thirds* of the tube may be taken away without altering its pitch. If the *double-octave,* as much as *three-quarters* of the tube may be removed and the note will be unaffected in *pitch,* though of course it will be proportionably more feeble in *force.*

359. In order to WHISTLE with the MOUTH, the lips must be pursed together. A small channel is thus made in the tongue, the tip of which is brought close to the front teeth of the lower jaw.

Lip-whistle.

360. The sound, in this case, originates at the lips from the impulsion of the breath against the external air, is reinforced by resonance in the cavity of the mouth, and modified in pitch by the play of the cheeks, lips, and tongue.

Cause of this whistle.

The *loudness* of the tone depends on the muscular energy of the whistler, and on the quantity of breath which passes through his lips in a given time.

361. The *compass* of the lip-whistle extends from E_2 to C_5, nearly three octaves; but very few persons can render distinctly above twelve or fourteen notes.

Compass of the lip-whistle.

The cause of sound in the lip-whistle is one of the most perplexing phenomena of acoustics. Savart says it is the result of alternate rarefac-

tions of air by the hot breath, and subsequent compressions by atmospheric pressure. This explanation, however, with all due deference to so honoured a name, cannot be admitted, inasmuch as the same sounds can be imitated mechanically without the aid of hot vapour. The whistling of wind through fissures and key-holes (356.) seems to be an analogous phenomenon. Whistling sounds of great force and purity may be obtained by means of a long gutta-percha tube communicating with a reservoir of compressed air, and terminated by a mouth-piece of flattened copper, fitted with a stop-cock. By opening the stop-cock more or less, air escapes through the copper chink with proportionate velocity; and by presenting this stream of air before a tube open at both ends or only partially closed, an excellent and forcible whistle may be obtained.

No less objectionable is the common notion that the labial whistle depends on the *vibrations of the lips;* inasmuch as a quivering lip is utterly incompatible with good whistling, and persons can whistle while their lips are covered with india-rubber or gutta-percha. If in whistling the lips vibrate at all, the motion is altogether the *effect* and not the *cause* of the sound produced.

Whistling through the teeth.

362. Some persons can whistle through their front TEETH, if they are not in close con-

tact with each other; and some others can whistle by forcing the breath between the teeth of the upper and lower jaw. In both these cases a channel is made along the tongue, the tip of which is made to approach the bottom row of teeth. The former of these methods of whistling is analogous to that of wind through a key-hole (356.). The latter resembles the production of sound by the flageolet (313.).

363. Whistling with the FINGERS may be performed in several ways. The easiest is the following:—Place in the mouth, against the tip of the tongue, the first and second finger of each hand, brought together so as to form a wedge (∧), against which let the lips press so as to prevent the loss of breath. By blowing with a jerk a whistle may be thus produced of very considerable force.

Finger-whistle.

364. In this case the fingers and lips make a kind of conical pipe. The

sound is generated by the laceration of the breath against the tip of the fingers or of the tongue*, and is reinforced by resonance from the cavity between the roof and floor of the mouth, and in some measure also by the channel formed by the fingers.

365. Similarly a person may whistle with the two index fingers, the two middle, the two third, or with the two little fingers. He may whistle even with one hand, by folding down the long finger and bringing together the tips of the first and third.

366. In order to make a whistle of the FISTS, the two thumbs should
Fist-whistle. be placed in juxtaposition; the palm of the right hand being laid over the palm of the left, and the ends of the fingers folded over the backs of the

* The fingers may be placed either *upon* the tongue, or *against* it, so as to make the extreme tip curl a little. The latter is, perhaps, the easier plan.

hands. The part contiguous to the two wrists must then be brought together, so as to form a sort of box. By blowing with a smart jerk *downwards* through the knuckles of the thumb, a whistle may be produced not unlike the barking of a dog.

Another way of arranging the hands for this whistle is to place them in the same direction over each other, and having folded down the first joints of one hand, to wrap those of the other over them. The fore-finger in both cases should be elevated as high as the thumbnails, that the aperture through which the breath is forced may not be obstructed.

367. The deep sound occasioned by this contrivance is due to the impulsion of the breath against the fleshy part of the thumbs, and its resonance in the hollow of the hands. As the air thus confined is not fugacious, it is capable of receiving a great shock, and hence the sounds produced are remarkably loud.

There are numerous other ways of whistling with the hand, one of which is to fold the fist

into a sort of funnel. By blowing with considerable force across the orifice where the thumb and fore-finger lap over, a loud sound may be elicited.

Another way is to fold the fist, and blow into a chink made between the last joints of the second and third fingers. These, however, are only modifications of what has been already explained, and present no new physical features.

SEC. V. MUSICAL INSTRUMENTS WITH BELLOWS.—THE ORGAN.

Organ.

368. The largest and most harmonious of all musical instruments is the organ, and the only one capable of awaking deep religious feeling. The flute is simple and pastoral, the trumpet martial and exciting, the violin capacious and lively, the piano pleasing and domestic, but the organ grand and sublime, filling the soul with awe, with transport, and profound veneration. Its effect is that of majestic mountain scenery, or the precipitate tumult of a cascade, or the commotion of a troubled sea booming at

the dusk of evening, or of a storm on the confines of a forest. It is musical thunder pealing in religious gloom, a sea of harmony, a Niagara of sound. When swelling into full force, making the solid walls of a cathedral tremble, and when speaking in a "still small voice," impressing the imagination with the idea of power in restraint and sublimity in humiliation.

369. The inventor of this master work is not known. The Bible calls Jubal, the son of Lamech, "the father of such as handle the harp and organ" (*Gen.* iv. 21.); but whatever might have been the instruments thus designated, there is no reason to believe they resembled those known to us by the same names.

The first account we have of any thing like an organ is by Archimēdés*, and the next by Vitruvius† who makes

* Archimēdés of Syracuse, the most famous of ancient mathematicians, was born B C. 287, and was killed by a Roman soldier when Syracuse was taken, B.C. 212. Nine of his works are still extant.

† Vitruvius, the author of a most celebrated trea-

mention of such an instrument worked by the pressure of *water* instead of air, and invented by Ctesibius*, a barber of Alexandria, about 260 years before the Christian era. From this time we have very little further information on the subject till the fourth Christian century, when St. Jerome † speaks of organs on the pneumatic principle, not as a novel invention, but as one well established. He particularises two distinctively, one at Jerusalem, "which might be heard on the Mount of Olives," and another, "with twelve pairs of bellows, which might be heard at the distance

tise on architecture, in ten books, died, at an advanced age, in the reign of Augustus Cæsar.

* Ctesibius, celebrated for his mechanical inventions, flourished in Alexandria about 250 B.C. He invented the clepsydra or water-clock, the hydraulis or hydraulic organ, and was the first to apply air as a motive power.

† St. Jerome, the most learned of the Christian Fathers, was born at Stridon, in Dalmatia, A.D. 340, and died in 420, aged 80. He was ordained a presbyter at Antioch (*in Syria*), and wrote a great number of works, most of which are still extant.

of a full mile." The first organ th
appeared in Europe was a present
the emperor Constantin Copronyme* t
king Pépin† in 757, and a few yea
afterwards Constantin Michel‡ made
similar present to Charlemagne§, th
son of Pépin. Organs were not em
ployed in churches before the 13t
century.

The largest church organ in London is
Spitalfields Church, the next is in Christ Churc
The largest in England is that at York Minste
which exceeds in size the organ erected in t

* Constantin, surnamed Copronyme, was the son
Leo the Isaurian, who usurped the empire of t
East. Constantin succeeded his father in 741, a
reigned thirty-four years.

† Pépin le Bref (i.e. *the Short*), King of France, a
first of the Carlovingian dynasty, was son of Charl
Martel (*i. e. the Hammer*). He reigned sixteen yea
(A. D. 752—768).

‡ Constantin Michel was son and successor of Co
stantin Copronyme.

§ Charlemagne was the eldest son of King Pép
and succeeded his father A. D. 768. He reduc
almost all Germany under his dominion, was a nob
patron of literature, and one of the greatest sov
reigns that ever reigned. He died at the age
seventy-two, after a reign of fifty-four years.

Music Hall of Birmingham. The *best* is reckoned the famous Temple organ, built by Schmidt.

The organ at Haerlem in South Holland is fitted with 60 stops and 8000 pipes. That at Seville with 100 stops and 5300 pipes. These, however, are mere dwarfs to the great organ exhibited in the Crystal Palace 1851.

Construction of the organ.

370. The organ may be considered as a collection of instruments brought under the finger of one performer. It consists of a great number of pipes of different sizes, some of wood and others of metal. These pipes are made to speak by compressed air applied to them through certain channels by the means of bellows, worked either by human force or by machinery.

Size.

371. The *size* of an organ is usually designated by the length of the largest pipe: thus an organ of 32 feet, of 16 feet, and so on, means one whose largest pipes are of those respective lengths.

372. Organ pipes may be divided into mouth-pipes and reed-pipes, each of which contains several different species.

§ 1. *Mouth-Pipes.*

373. MOUTH-PIPES are either of wood or metal, differing somewhat in shape, but constructed on the same principle.

374. A WOODEN MOUTH-PIECE consists of a right-angled tube, formed of four plane boards glued together; the cross section of the pipe being oblong.

At A A the pipe is either open, or stopped by a plug (T), technically called a *tompion.*

The other end is closed by a block (B), on which the walls of the pipe are glued, except only at a narrow aperture across the front wall, called the *mouth* (*m*).

This *mouth* is formed by the front wall being levelled from *l l* towards the block, so as to form a sharpish edge at E, called the *upper lip.*

A small tube (P) is fitted into the

bottom of the block, through which the wind enters.

The wind from the bellows having entered this tube, is forced in a thin stream against the *upper lip*, and is thrown into vibration by the percussion in precisely the same manner as the breath of the performer is lacerated by a flageolet (313.).

375. The *loudness* of an organ-pipe depends chiefly on the size of the aperture through which the wind enters.

Loudness.

376. The *pitch* depends on the *length of the pipe;* consequently stopped pipes are rendered more sharp by pushing the tompion further home. The same pipe is capable of producing more than one note, according to the force of the blast. The lowest, or fundamental note, requires a more moderate current than its harmonics. The harmonics of a stopped pipe are the same as those of a Pandean reed (294.). Those of an open pipe are the same as the harmonics of a flute (307.).

Pitch.

In practice not more than four or five harmonics can be produced from any reed or pipe.

377. If the tompion be removed, a pipe will give the *octave* of the former note; a stop, therefore, of *open pipes*, must be double the length of shut ones in order to speak in unison.

378. The *quality* of tone is principally influenced by the *material* employed in the construction of the pipes. Mahogany and wainscot pipes have a clearer tone than those of fir and pine, but the latter are the more mellow. Timbre.

379. METAL mouth-pipes are made on the same principle as wooden ones. They consist of a cylindrical tube, the *mouth* being formed by flattening or pushing-in the part which forms the *mouth and lips*. The inclination of the metal from *l* to the mouth is at an angle of twenty-two degrees, and the edge is a little cut away. Metal pipes.

The foot or cone of the pipe is open at the bottom or apex, but closed by a metal plate, called the *languet*, at the top, leaving only a small aperture or mouth for the wind of the bellows to pass into the upper or vocal part of the pipe.

The wind which enters at the apex (A), breaks itself against the upper lip (*l*), and is thrown into vibration as in the previous instance (374.).

The woodcuts representing the cone of these pipes show the *interior* from the languet upwards.

Metal pipes may be either stopped or open, and the remark made in No. 377. is equally applicable to either.

380. Metal pipes are furnished with
Ears. *two ears*, EE (*see* 379.), one on each side of the mouth. The pipe is rendered more *flat* by bending the ears *nearer to the mouth*, and more *sharp* by *driving* them further apart.

Open metal pipes are tuned by pressing-in the metal at the *top of the pipe* to flatten the tone, and by driving it out to sharpen the pitch.

§ 2. *Reed-Pipes.*

381. REED-PIPES are made to speak in a manner very different to those already described. The rationalé of *mouth-pipes* resembles that of the flageolet, in which the wind is thrown into vibration by striking against the sharp edge of the *upper lip*. That of *reed-pipes* resembles the mechanism of the hautboy and bassoon, where the air is made to vibrate by the reeds which form the mouth-piece.

382. In the subjoined woodcut the part *a a b* represents a brass tube, having a longitudinal narrow opening in front, over which lies a thin slip of metal (*l*), called a *languet* or tongue. This tongue is rigidly fixed at the upper extremity, but is free at the bottom. The whole apparatus is firmly fixed in a block (B). F represents the reed,

the apex of which passes through the

block. SS is a stout piece of wire, called the *tuning-spring;* it presses against the languet to keep it close. By being drawn up it gives the tongue more liberty, and makes the note *flatter*. By being forced down it makes the languet shorter, and renders the pipe more *sharp*. The outer tube (CCCC) is called the socket.

The engraving represents the *interior* of the socket.

383. The wind of the bellows enters at the apex (A), and fills the socket; presses against the languet, and shuts it. As this languet is elastic, it springs back and admits a little air; is again shut and again springs open, giving a vibratory motion to the air in the

socket, which makes its way gradually into the vocal tube and produces the note which the pipe utters.

384. The more a languet is curved the louder the voice of the pipe, but the flatter the note. It is more *loud*, because the "spring" gives the air more violent shocks; it is *flatter*, because the tongue vibrates less easily.

Some reed-pipes have no languet or tongue, but a thin elastic pipe instead, called a *reed*, which is split along the middle to a certain length so as to vibrate.

§ 3. *Promiscuous Remarks on the Organ.*

385. The organ is not content with one pipe for each note; it has many, in order to imitate different instruments. The pipes which represent any given note are arranged in rows, each row being called a *stop*. By a peculiar machinery any one or more of these pipes may be brought under the hand of the organist, so that the effect of one instrument or of many in combination can be produced. Some

Organ stops.

of the stops are named from the resemblance of their tone to that of certain musical instruments, as the *cornet*, *trumpet*, *bassoon*, *flute*, &c. The most important, and those most frequently employed are the *open* and *stopt diapasons*, the *principal* and the *fifteenth*.

The very large pipes are not placed in rows, but are disposed wherever a convenient space can be found.

386. The deep bass pipes are sometimes 32 feet long, the others decrease by moieties in the following order, 32, 16, 8, 4, 2, 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$. The 32-feet pipe renders CC two octaves below what is termed "middle C." The small pipe, $\frac{1}{8}$ of a foot or $1\frac{1}{2}$ inch long, gives C eight octaves higher. (*See* 161.)

387. The KEYS of an organ resemble in appearance those of a pianoforte, but their action is essentially different. The keys of a piano are connected with little hammers, which strike against the strings respectively stretched above them; but an organ

Organ keys.

has no strings, and its keys no hammers.

The use of organ keys is to open the valves which admit the wind of the bellows into the pipes required to speak. When a key is pressed down, the valve of the corresponding pipe is opened, the air rushes in and renders the tube vocal. When a key is *not* pressed down, the valve is closed, and no wind can enter the pipe to make it speak.

388. There are frequently *three* KEY-BOARDS to a church organ, two of which contain four and a half octaves, and the third or upper rank three octaves. These boards are arranged, like stairs, one above the other. In some organs there are four, and occasionally as many as five, ranges of keys. Organ key-boards.

The key-boards of the Birmingham organ contain five and a half octaves, those of the York organ six.

389. When there are three key-boards the FIRST is the *long* scale, extending generally from double G to F

in alt.; the SECOND is the *short* scale, which extends from double C to the same F in alt.; and the THIRD is the *short octave*, scale going down to double G by what is called "a short octave:" *i. e.* there is a finger-key below C C which sounds double G instead of double B; while the finger-key, which should, from its position, give C C♯, gives double A.

The three key-boards are very often thus denominated: the *lowest* set of keys is called the CHOIR ORGAN, and contains the stopt *diapason*, the *dulciana*, the *principal*, the ~~*flute*~~, the *twelfth*, the *bassoon*, and the ~~*vox humana*~~; the *middle* set of keys is called the GREAT ORGAN, the principal stops of which are the two *diapasons*, the *principal*, the *twelfth*, the *fifteenth*, the *sesquialter*, the *mixture*, the *trumpet*, the *clarion*, and the *cornet*; the *uppermost* set is called the SWELL, and comprises the two *diapasons*, the *principal*, the *hautboy*, the *trumpet*, and the *cornet*.

Foot-keys.

390. Besides these key-boards there are rows of pedals or foot-keys, which act on the larger pipes. The effect of these pedals is to double the bass in the octave below.

391. Organ pipes are generally too *sharp* in hot weather, and too *flat* in frost; the difference between the two extremes being nearly a quarter of a tone. The reason is this: an increase of temperature increases the *elasticity* of the pipes; in consequence of which, they vibrate somewhat more quickly, and render a higher note.

Organs sharp in summer.

§ 4. *Miscellaneous Instruments with Bellows.*

392. The principle of a BARREL-ORGAN is the same as that of a common organ, the main difference being the absence of key-boards, the place of which is supplied by pins and staples disposed on the surface of a cylinder called the *barrel.* The bellows are worked and the barrel made to revolve by means of a winch. As the pegs are brought in contact with the different levers, they admit the wind

Barrel-organ.

into the corresponding pipes and make them speak. When an air has been played and another is desired, the barrel must be shifted according to a table attached to the organ, bearing the name and number of its different pieces. By this artifice every time the cylinder is shifted it presents to the levers a different arrangement of pegs.

Some barrel-organs are furnished with metal tongues like a musical snuff-box, instead of pipes.

393. The harmonicon, or, as it is more frequently called, the ORCHESTRINA, is a large barrel organ, furnished with additional pipes to imitate various wind instruments, and with an apparatus to produce the effect of drums, triangles and cymbals. The combined effect of this powerful instrument is designed to resemble that of a full military band.

Orchestrina.

394. The HARMONIPHON is played with keys, like a pianoforte, and is a kind of organ furnished with

Harmoniphon.

thin metallic plates or tongues, like a musical snuff-box, instead of pipes. The air which acts on these vibrating tongues is generally blown by the mouth through an elastic tube.

The harmonicum, eolophon, and seraphine, are only modifications of the same instrument.

395. The ACCORDION is a keyed instrument whose tones, like those of the harmoniphon, are generated by the play of wind upon metallic reeds. It is a small wind-chest, the sides of which are made to fold and expand like bellows. On the top there are apertures, in which the metal reeds are inserted and upon which they play. Each key commands two successive notes, because it plays on two apertures, one of which is opened when, by expanding the accordion, the wind is *drawn in;* the other when the wind is forced out by *closing* the instrument. In addition to the keys there is a slide which opens upon reeds attuned to the

Accordion.

tonic * and dominant †, by opening which the air has an harmonic ‡ accompaniment. The bottom of the wind-chest is furnished with a large key, by which the chest may be opened, and suddenly exhausted or filled, as need requires. A good accordion commands from two to three octaves in the diatonic scale. §

396. The TWANG of cheap ACCORDIONS arises from a defect in the metal reeds. Instead of closing the apertures as they ought, they beat against them, and thus produce a harsh tinny clatter.

Clatter of accordions.

397. The CONCERTINA is a superior sort of accordion, hexagonal in shape, and played with stops

Concertina.

* Tonic, *i. e.* the fundamental or principal sound of a note, or its *octave* (*see* 162.).

† Dominant is the fifth from the tonic.

‡ Harmonics are derivative sounds, produced from the tonic by varying the blast of a pipe or the length of a string.

§ The diatonic scale is that in which the notes succeed by tones and semitones in the following order: T, T, S, T, T, T, S (*see*. 162.).

inserted in the top and bottom of the instrument. Each stop gives uniformly the *same* note, whether the wind-chest be expanded or compressed. The concertina is occasionally introduced into the concert-room, and is capable of great execution.

398. The BAGPIPE is a musical instrument of great antiquity. It is of Arabian origin, although the Romans call it an Etruscan invention. It is now chiefly found in Scotland and Ireland where it is a great favourite. It consists of two parts: first, of a sheep-skin bag, inflated by means of a tube inserted in the sac and furnished with a valve or stop-cock to prevent the escape of the wind; and, secondly, of a pipe and two flutes. The pipe is furnished with a reed, into which the performer blows; and each flute is pierced with four finger-holes. The bass flute is called the *drone*, and the other the *chanter*. In order to make this instrument speak the bag must be

Bagpipe.

placed under the left arm and squeezed, upon which the wind rushes into the flutes and is allowed to escape through different finger-holes, according to the pleasure of the piper.

Different species.

399. There are several species of bagpipes; as, for example, the soft and melodious Irish bagpipe, with two short *drones* and a long one; the Highland bagpipe, with two short drones only, the music of which is extremely loud; the Lowland bagpipe, a powerful instrument played with bellows; a small bagpipe with a *chanter* only about eight inches long; and some other varieties of less usage.

400. The sound of the bagpipe, like that of the labial whistle (360.), and of the howling of wind through fissures and key-holes (356.), is occasioned by the shock given to the air by the wind pressed from the leathern sac. The average compass of the instrument is about three octaves.

CHAPTER VII.

PRACTICAL ACOUSTICS.

401. It has been already shown that whenever sound can diffuse itself freely round its centre of propagation, it loses in *intensity* what it gains in extent (105.). This rule, however, does not apply to sounds conveyed through a column of air *enclosed in a tube*. A person may transmit a sound no louder than a whisper, to an almost indefinite length by means of a cylindrical tube. Biot* and Martin conversed by whispers, one night in Paris, through an

* Biot, see *note* at the foot of p. 100.

empty iron water-pipe 3000 feet in length.

402. The scientific have availed themselves of this important fact in order to transmit the human voice to considerable distances, and to assist those whose sense of hearing is impaired.

The principal acoustic instruments in common use are—(1.) the speaking-tube, more correctly called the tube of communication; (2.) the speaking-trumpet; and (3.) the ear-trumpet.

SEC I. § 1. *The Speaking-Tube or Tube of Communication.*

403. The tube of communication, frequently called distinctively *the acoustic tube*, is extensively used in coffee-rooms, taverns, houses of business, counting-rooms, offices, and warehouses, for conveying orders to the attendants and journeymen situated in different parts of the establishment. It is also occasionally employed on board ship to transmit messages from the

captain's cabin to the mast-head. Dr. Herschel has attached one to his 40-feet telescope, for communicating his observations to an assistant who sits under cover near the instrument.

404. It is by no means easy to give a satisfactory explanation of this simple phenomenon. Physiologists in general suppose that the tube serves to *reflect* the rays of sound, and present them in bundles at the further extremity. There may be some slight truth in this conception, but it is by no means free from very grave objections, and it is utterly irreconcilable with the fact that a tube of communication answers its purpose quite as well when its interior is rough or lined with woollen cloth as when it is smooth and highly polished. In other words, the best reflecting surface has no apparent advantage over the worst.

Theory.

405. The following combination of causes may perhaps be less objectionable:

1st. The sound being limited to the hollow of the tube, does not *diffuse itself* in open space, but is propelled in one direction only; and, as air is very elastic, it acquires in this direction the sum of the force which would be otherwise spread in concentric circles round the centre of propagation.

2dly. The column of air confined in the tube is more *tranquil and uniform* than the external air; it is not affected by wind or convective currents; it is not able to shift its level every time its density is increased or diminished; consequently, no part of the sound is lost or weakened by interference.

3rdly. The air in the tube is capable of receiving from the voice of the speaker a *stronger impulse* than air which is more fugacious. It cannot yield so readily and slip away, but is compelled to abide the full force of the shock imparted to it.

4thly. The friction and beating of the sound-waves against the metal

walls excite the *resonance* of the tube, which serves to strengthen considerably the force of the sound.

5thly. *Reflexion* may also contribute its share to the phenomenon. As the waves impinge against the sides of the tube they are doubtlessly reflected more or less; and being driven back on other waves, deepen their undulations.

406. Sounds are propagated along a WALL in much the same manner as through a tube. Thus the noise of a gardener's hammer is conveyed with great distinctness from one extremity of a long wall to the other. In this case, the divergence of sound on two sides is prevented by the trough or angle formed by the wall and ground; and the original noise is strengthened by the resonance.

A wall conveys sound.

407. Dr. Hutton * says, when on a

* Dr. Charles Hutton, of Northumberland, was the author of a Course of Mathematics; Mathematical Tables; a Mathematical and Philosophical Dictionary, &c. &c. (*He died* 1823, *aged eighty-six.*)

visit to Wm. Pitt, Esq., of Kingston, in Devonshire, he often heard a mere whisper transmitted from one end to the other of a garden-wall above 200 feet in length, situated in the pleasure grounds of that estate.

Dr. Hutton at Kingston.

408. At Carisbrook Castle, Newport, in the Isle of Wight, there is a WELL 210 feet deep, and 12 feet in diameter. Its walls are covered with smooth plaster. If any one drop a pin into this well, he will distinctly hear it strike the water. The sides of the well form a veritable acoustic tube, which prevent the diffusion of the sound, and the hard plaster is sufficiently elastic to increase by resonance the force of the report.

Carisbrook well.

409. It is well known that if any one SPEAK over the mouth of a WELL, he will hear the echo of his voice with remarkable loudness. The sound enters the well, strikes against the water, is reflected upwards,

Speaking over a well.

puts the solid masonry into a state of vibration, and, strengthened by resonance, returns to the embouchure. The well acts, therefore, as a tube of communication between the echo and the speaker.

410. Probably the oracular responses at Delphi* and in the cave of Trophonius†, were delivered through tubes of communication by confederate priests; and the speaking instruments of the middle ages were, without doubt, ingenious combinations of pipes and stops, concealed by the external semblance of a human head.

* Delphi, a town in Phocis, contained the most celebrated oracle in all Greece. The priestess who delivered the responses was placed on a tripod over a well; and the words she uttered were taken down and turned into verse by a person employed for the purpose.

† The cave of Trophonius was in Bœotia, in Greece. He who consulted this oracle had to pass through numerous rites and ceremonies, many of which had a soporific or stupefying effect. He was ultimately dragged, feet foremost, into a hole underground, where he received the oracular response.

§ 2. *Speaking-Trumpet.*

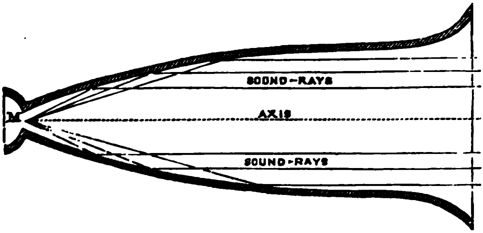
411. A speaking-trumpet is simply a metal tube of a conical shape, having the length very great compared to its breadth. The smaller end is furnished with a mouth-piece adapted to surround the lips of the speaker and to confine his voice. The other extremity is spread into a bell shape by the outward curvature of the metal walls.

Speaking-trumpets are very commonly employed on board-ship and at public fairs.

412. This instrument increases sound: 1st, because the column of air confined by the sides of the tube cannot slip away from the shock of the speaker's voice; 2ndly, the sound of the voice in its progress through the tube is strengthened by resonance; and, 3rdly, the shape of the instrument is such as to reflect sound in *parallel* instead of in *diverging* rays; in consequence of which, a

Explained.

large number move simultaneously towards the person at whom the trumpet is directed.



The proper form of a speaking-trumpet is that given in the engraving, called a *parabŏla.* The point M (at the orifice of the mouth-piece) is called the focus, and the dotted line the axis, to which the sound-rays are parallel when they issue from the trumpet.

413. Although the third reason stated in the above paragraph is much the most plausible, and is generally given by physiologists as sufficient of itself to explain the phenomenon, yet it can be at most only subsidiary, inasmuch as a speaking-trumpet propagates

sound with equal force whether its sides be highly polished so as to form an excellent reflecting surface, or whether they be rough, painted, or even lined with coarse woollen cloth.

Kircher's speaking-trumpet.

414. Such is the force given to the voice by the speaking-trumpet, that Kircher*, by means of it, about the end of the 17th century, read the litany at a convent situated on the top of a hill, to a congregation of 1200 persons, who heard it at the distance of from two to five Italian miles. With a well-constructed trumpet 24 feet long a strong voice could make itself heard at sea for about three miles.

According to Muschembröck †, a speaking trumpet 4 feet long will transmit the voice

* Athanasius Kircher was a learned German Jesuit, an excellent orientalist and mathematician. His works occupy twenty folio volumes, eleven quarto, and three octavo. He lays claim to the invention of the Æolian harp, and of the speaking-trumpet. (*He died* 1680, *aged seventy-five*.)

† Peter van Muschembröck was born at Utrecht,

2500 feet; one 16 feet long will transmit it 8000 feet; and one 24 feet long 15,000 feet.

§ 3. *Hearing-Trumpet.*

415. The hearing or ear-trumpet is employed by those whose sense of hearing is impaired. The application of this instrument is the reverse of the speaking-trumpet. The deaf man places the small end in his ear, and the speaker's voice enters at the large end. It is of little moment whether an ear-trumpet be long or short, straight or crooked; whether it be made of metal or wood, india-rubber or gutta-percha, ivory, horn, or any other convenient material. The chief object should be to make the pavilion sufficiently large to collect a considerable number of sound-waves, and then cause them to condense their amplitude more and

in the Netherlands, A. D. 1692, and died 1761. He was a Fellow of the Royal Society of England. His two principal works are called (1.) *Elementa Physicæ*, and (2.) *Compendium Physicæ experimentalis.*

more till they ultimately enter the ear of the person using it.

See note to No. 106. The air that enters the trumpet is diffused over the large square described on A C or A D, and is condensed at the small end into the small square described on A B; consequently, the force of the impetus must be very greatly augmented.

§ 4. *The Stethoscope.*

416. The stethoscope*, invented in the early part of the present century by Dr. Laennec †, is an ingenious application of practical acoustics. The stethoscope is a small cylinder of some fine-grained wood, such as box, cedar, or maple, furnished with a funnel at one end and a round ivory perforated plate at the other. This instrument is used by medical men for the purpose of what is termed *auscultation*; that is,

* Stethoscope is compounded of the two Greek words στῆθος σκοπέω (*I explore the chest*).

† Professor Réné Théophile Laennec, a French physician, was born at Quimper, the capital of Finisterre, in 1781, and died in 1826.

listening to the sounds made by the heart or by the passage of the breath and blood in the throat, chest, and other cavities of the human body. The wide end is applied to the part of the body to be sounded, and the other end held to the ear of the physician, who by this means has a clear perception of the sounds caused by the action of the lungs, &c., and can judge whether the part to which his attention is directed be healthy or diseased. The inroads of consumption, inflammation in the linings of the body, and other organic derangement may be thus detected with readiness and tolerable certainty.

417. The explanation already given of tubes of communication (405.) will apply to the stethoscope; but its use is not so much to increase the force of the diagnostic sounds as to isolate them; and probably it owes its popularity to convenience more than to any physical property it may possess. Often it would distress a patient to

have the ear and cheek of a medical man reclined upon the bare chest, loins, or back; and sometimes the state of the skin might render such an application inexpedient; in both cases the use of the stethoscope answers every purpose without shocking the modesty of the patient or endangering the health of the physician.

SEC. II. SOUNDING-BOARDS.

Watch or tuning-fork applied to a table.

418. Every one must have noticed that the ticking of a WATCH is much louder on a TABLE than in the pocket, in the hand, or suspended in a detached position on a hook; so also when a tuning-fork is excited, the sound is very feeble till the tip of the handle is applied to the body of a violin or to some other surface easy of vibration. The augmentation of sound in both these instances is due to resonance. The sonorous vibrations created by the watch and

tuning-fork put the wood upon which they are placed into a similar state of vibration, and its simultaneous shocks against the superincumbent air greatly strengthen the tone of the original note, and render it more audible.

Especially on an empty box.

419. This is especially the case when the watch or tuning-fork is placed on an *empty* box or table containing empty drawers, because the air in the box or drawers receives corresponding vibrations from the wood, like the air in the "belly" of a violin.

Sounding boards of musical instruments.

420. Sounding-boards are employed in all stringed instruments of music. In a violin, violoncello, double-bass, Æolian harp, guitar, &c., the wood-work which forms the body of the instrument constitutes the sounding-board. In pianofortes a thin board of some light wood is spread over the strings to increase the volume of sound. The vibrating strings first act upon the air

within the case; this air impresses its motion on the sounding-board; and the sounding-board communicates its vibrations to the external air.

421. In the ancient theatres, which were exceedingly large, there were SOUND REFLECTORS disposed round the actors to augment the loudness and brilliancy of their voice. Every one knows that certain sounds of the voice become more intense when we speak towards a large open vessel, because the air of the vessel vibrates in unison with the voice. Savart * conceived a very simple means whereby the voice is made to assume a wonderful roundness and force. His contrivance was merely a larger cylinder moving on a pivot, open towards the speaker and either close or open at the other end according to option.

Sound reflectors.

422. We never now make use of reflectors like those of the Greek theatres; but SOUNDING-BOARDS

Pulpits. Platforms. Stages.

* Savart, see *note* to p. 118.

are pretty generally employed to assist the voice of public singers and speakers. Clergymen are elevated in a pulpit which ought always to have a false bottom or double floor. Actors speak from a stage; public orators from a platform or hustings. In all these cases the volume of the voice is increased by the resonance of the vibrating floor.

423. In Italy orchestras are constructed with especial reference to the advantage to be derived from a reciprocating floor. The platform on which the musicians are placed is spread over a hollow vault or cave, the points of support being as few as possible, in order that its vibrations may not be interrupted. This platform receives from the musical instruments a vibratory motion, imparts the same to the air between it and the floor of the building, and the whole combined gives a powerful impulse to the air of the concert-room.

Italian orchestra.

424. Even in England, where the practical part of acoustics is sadly disregarded, all musicians know if they sit on a soft cushion or sofa, the sound of their voice or instrument is much more feeble than when they stand on a platform or sit on a hard seat. Not so much because the cushion stifles the echo or resonance, as because it does not vibrate. The musician, therefore, who uses a cushioned chair or sofa loses the important co-operation of a vibrating seat, and buries much sound in the one he injudiciously employs.

Seats for musicians.

Orchestras are sometimes improperly furnished with rush or cane chairs, I suppose for the sake of economy; for surely it must be "poverty and not the will consents" to an arrangement so injudicious.

CHAPTER VIII.

ECHO.

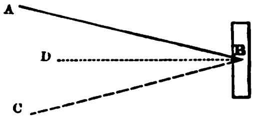
425. When sound, in the course of its propagation, meets with an obstacle of sufficient dimensions it is reflected, as a wave of water is thrown back when it beats against a rock or shelving shore.

426. The *velocity* of the reflected sound is in every case equal to that of the direct sound. Velocity of echo.

427. If a sound strike against an obstacle *perpendicularly* it is reflected

in the same line; if not, it flies off in an opposite direction, in such wise that the angle of *reflexion* is equal to the angle of *incidence*. Thus:

Manner of reflexion.



Suppose AB to be a sound-ray striking *obliquely* against the object B; it will not, in such case, be reflected along the same line BA, but will diverge in the direction of BC. If a perpendicular (BD) be raised from the point B between these two lines, it will be found that the angle of reflexion CBD equals the angle of incidence ABD.

428. The cause of echo is not yet well understood; it is probable that the impact of the sound-waves causes the opposing surface to vibrate in much the same way as a watch or tuning-fork sets in vibration a "table of harmony," or the voice of a public speaker the platform on which he stands. The vibrations thus elicited

create a *new sound*, sometimes in unison with the direct sound, and sometimes its 3rd, 5th, 10th, or some other harmonic. Such part of the direct sound as is not absorbed by the reflecting surface amalgamates with the new vibrations; and the two constitute the echo; so that echo is not the mere replication of the same veritable sound which struck against the opposing obstacle, but the direct sound in combination with a new sympathetic one provoked from the echoing surface itself.

429. There are many striking facts in corroboration of this hypothesis, amongst which the following deserve attention:—(1.) The vibration of an echoing surface is in many cases sufficiently sensible to be *actually felt;* (2.) it is not necessary for the reflecting surface to be either *hard* or *smooth*, like a mirror, and therefore there can be very little resemblance between the reflexion of sound and the reflexion of light; (3.) every elastic substance which

stands in the path of a sound-ray partakes in a measure of its vibrations; (4.) echo is very often an *harmonic* of the direct sound, but if it were only the original rays reflected, it would in every case be a perfect unison; lastly, echo is frequently *louder* than the direct sound. These premises seem sufficient to prove that echo is something more than mere reverberation.

Grand division of echoes.

430. Echoes may be divided into SIMPLE and COMPOUND. Each of these may be subdivided into MONOSYLLABIC and POLYSYLLABIC.

Sub-division.

431. SIMPLE echoes repeat a sound but once only. COMPOUND echoes more than once.

432. A simple *monosyllabic* echo repeats *once* a simple sound, such as a single syllable or single note.

433. A simple *polysyllabic* echo repeats once *two or more* syllables or notes.

434. A compound *monosyllabic* echo repeats *more than once* a simple sound,

such as a single syllable or single note.

435. A compound *polysyllabic* echo repeats more than once *two or more* syllables or notes.

436. Besides these four, there are three other sorts of echo:—The HARMONIC echo, which repeats the original sound in a different tone, pitch, or key; the ELLIPTICAL echo; and the echo called RESONANCE.

SEC. I. § 1. SIMPLE MONOSYLLABIC ECHOES.

437. In order to obtain a distinct simple echo, there must be, 1st, at least *one* reflecting surface; 2ndly, if there be two or more reflecting surfaces, they must be so placed that the reflexion from each may strike the ear at the same moment; and, 3rdly, the surface or surfaces must be so remote that the echo cannot mingle with the primitive sound.

Places favourable to echo.

438. The PLACES most favourable to the production of simple echo are deep wells, caverns and grottoes, ruined abbeys, the areas of vast halls, long winding passages and cathedral aisles, isolated trees, mountains, banks of ice, and piles of buildings. These objects present insurmountable barriers to the onward progress of the sound-waves, which, being unable to continue their march, are both reflected as the rays of light by the impenetrable metal on the back of a looking-glass, and also by their impulsion elicit from the obstacle itself a fresh sound, which they either cause to succumb, or into which they merge.

Interval before an echo is heard.

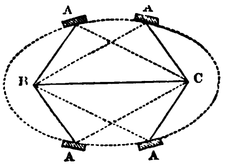
439. The interval occupied between the production of a sound and its return to the point of propagation is equal to the length of time required by sound to travel over *twice the entire distance* between the observer and the reflecting surface.

Consequently, the depth of a well or the distance of an inaccessible rock which causes an echo may be computed by noting accurately the interval between any given sound and its echo; for, as the sound-waves must advance to the reflecting surface, and return again to the observer before any echo can be heard, the interval must evidently equal the time required to traverse twice the distance of such obstacle.

Serve to measure distances.

440. Sometimes two or more obstacles concur to produce one and the same echo. Where this is the case, the several obstacles ought to form parts either of an *ellipse* or of a *circle*.

Simple echo from several obstacles.



Thus: Let A A A A be four reflecting surfaces so placed as to form parts of an ellipse.* Let B and

* An ellipse is an oval figure (see p. 12. *note*). Its two diameters are called *axes*. The *foci* of an ellipse

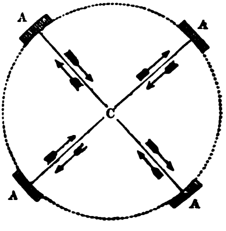
C be what are termed the two *foci* of this ellipse. If a sound proceed from either of these foci, it will be heard *twice* at the other. It will arrive first *directly* along the straight line BC, and again *indirectly* along the reflected rays BA, AC.

Interval before the echo.

441. The interval which will elapse between these two sounds will be equal to the difference between the time which the sound requires to pass from B to C directly, and that required to go first from B to A and then from A to C.

Simple echo from several objects at once.

442. Suppose, instead of forming an ellipse, the several objects compose parts of a circle; then a



are two points near the ends of the longer axis, such that, if two straight lines be drawn from them to any point in the circumference, they shall together equal the longer axis.

person at the centre C will hear the echo of his own voice from the simultaneous reflexion of the opposing objects at A reflected to the centre where he stands.

443. The interval, in this instance likewise, between the primitive sound and the echo will be equal to the time required by the sound-waves to go from C to A and back again.

Interval before the echo is heard.

444. If the four objects in the preceding examples be in such a relative position as to form no part either of an ellipse or of a circle, or if either the sounding-body or the listener be in any other position except at the focus or centre, the different reflected rays will not reach his ear *simultaneously*, and the echo will be either compound or confused.

Confused echo.

In the instances referred to above we have supposed *four* objects concurring to produce the same echo; it need scarcely be added, that the

number of obstacles is a matter of entire indifference. Two walls or houses, or any other number, would do as well, provided the observer place himself in the *focus* of the ellipse, or in the *centre* of the circle.

Echo at sea.

445. It is often said there is no echo in the OPEN SEA; this, however, is not correct, for experience testifies that echo may proceed from the thick clouds, the sea-waves, or from the sails of a ship. The report of a gun when a sailor shoots at a sea-bird is often repeated by the surging billows leeward of the vessel; and words uttered loudly through a speaking-trumpet are occasionally repeated by the convex side of an opposite sail. In both cases the wind blows, of course, towards the gunner or the speaker.

There is no echo at sea without a stiff wind, for both surging waves and inflated sails presuppose the presence of wind.

Dr. Arnot and the marriage peal.

446. Dr. Arnot relates an anecdote confirmatory of sea-echo. "It happened once," writes the Dr.,

"on board a ship, sailing along the coast of Brazil, 100 miles from land, that the persons walking on deck, when passing a certain spot, heard most distinctly the sound of bells varying as in human rejoicing. All on board listened and were convinced, but the phenomenon was mysterious and inexplicable. Some months afterwards it was ascertained that the bells of the city of St. Salvador, on the Brazilian coast, had been ringing that very day on the occasion of a festival. The sound had, therefore, travelled over 100 miles of smooth water, and, striking the wide-spread sails of the ship, rendered concave by the breeze, had been brought to a focus, and rendered perceptible to all on board."

SEC. I. § 2. SIMPLE POLYSYLLABIC ECHOES.

447. A simple POLYSYLLABIC ECHO is one which **articulates** *two or more*

syllables without repeating them a second time.

Echo at Selborne.

448. White* records an echo of this description near Selborne, in the King's field leading to Norehill, which used to repeat ten syllables, and the last as distinctly as the first, if quick dactyls were chosen; as for example,

"Knōw yĕ thĕ lānd ŏf thĕ cȳprĕss ănd mȳrtlĕ?"

The reverberation took place from a stone building at the distance of 258 yards. Some time after the discovery of this echo, a hedge planted for the protection of a hop-garden obstructed the voice of the speaker, and silenced the echo.

Lago del Lupo.

449. On the banks of the Lago del Lupo, above the Falls of Terni, in Italy, there is an echo which

* Gilbert White, M.A. (Oxford), a writer on natural history and antiquities, was born at Selborne, in Hampshire, 1720, and died 1793. He devoted his leisure to a work entitled *Natural History and Antiquities of Selborne.*

articulates fifteen consecutive syllables.

450. In Woodstock Park, Oxfordshire, where the beautiful Rosamond was confined by Henry II.*, and assassinated by his jealous queen, is an echo which repeats seventeen syllables by day, and twenty by night. It may easily be understood how this voice has become superstitiously connected with the disembodied spirit of the unhappy captive. The reason why more repetitions take place by night than by day, is that at night the air is more *uniform*, because the sun no longer heats one part of the soil more than another, so as to produce ascending and descending currents. It is also more *dense*, and

Echo at Woodstock.

* Henry II., jaded by the evil temper of his wife Eleonore, sought social comfort in the company of the beautiful Rosamond, the daughter of Walter Clifford. For the sake of concealment, he kept her in the labyrinth at Woodstock; but the jealous queen discovered her retreat, and compelled her to drink poison A. D. 1173.

consequently more favourable to the propagation of sound (85. 87.).

451. There is a simple polysyllabic echo on the north side of Shipley Church, in Sussex, which renders as many as twenty-one consecutive syllables.

Shipley echo.

452. The echo of Westminster bridge, London, has attained dramatic celebrity. It is heard in the arch-roofed sitting-places, from the dry arches below, and *vice versâ*.

Westminster bridge.

453. At Nancy, in France, there is a simple echo which will repeat accurately an Alexandrine verse.

Nancy echo.

454. To these several examples one more may be added, not so much for its surpassing capacity as for its droll celebrity. In the cathedral of Girgenti, in Sicily, the slightest whisper is borne with perfect distinctness from the great western door to the cornice of the high altar, a distance of 250 feet. By a curious coincidence the precise focus of di-

Echo of Girgenti.

vergence at the former station was originally selected for the place of confessional. Secrets never intended for the public ear were communicated by the tell-tale echo across the church, to the great dismay of the confessors and the scandal of the people; nor was the cause discovered till one day a man at the further extremity of the cathedral overheard his own wife making avowal of her infidelity. The husband being unable to keep the secret thus strangely divulged, the confessional was forthwith removed to another part of the building.

455. Simple polysyllabic echoes depend solely on the *distance* of the echoing surface. The last of all the syllables to be repeated must be pronounced by the speaker before the echo of the first reaches his ear; otherwise the echo will not be distinct and intelligible. In the ordinary manner of speaking, a person pronounces about eight syllables

Cause of polysyllabic echo.

in a second, and sound travels 1120 feet in the same time; consequently, if the reverberating obstacle be only 140 feet distant, it can repeat but one syllable; if it be 280, it will return two syllables; if 560 feet, three syllables; and so on, 140 feet being allowed for each separate syllable.

The reason is manifest; the sound has to go and return before an echo can be heard. As sound travels 1120 feet in a second, it must have a clear 560 feet to advance, and 560 feet to return in order to make up a second; but as all the syllables to be echoed must be pronounced by the speaker before the echo of the first is heard, the time required to utter the syllables must be deducted. Suppose, therefore, eight syllables to be articulated in a second, 560 feet in a direct line must be allowed for the utterance of these syllables, and 560 more for the repetition of them by the echo; consequently the obstacle must be at least 1120 feet distant. If *four* syllables be echoed, the reflecting surface must be half as far off, or 560 feet; if *two* syllables, it must be a quarter that distance, or 280 feet; if only *one*, it must be half-a-quarter, or an eighth, of that distance, that is 140 feet.

SEC. II. § 1. COMPOUND MONOSYLLABIC ECHOES.

456. A COMPOUND MONOSYLLABIC echo repeats *two or more times* one syllable or one note. Thus, in the centre of Königsplatz, at Cassel, in Germany, where six streets meet in a large oval, there is an echo which repeats a sound six times distinctly. Cassel echo.

457. At the classic tower of Cyzĭcus*, on the Mysĭan bridge, in Asia Minor, a word used to be echoed (according to tradition) seven times. Echo of Cyzicus.

458. At Thornby Castle, Gloucestershire, is an echo which repeats ten times distinctly; and at Brussels these is one which repeats a word fifteen times. Echo at Thornby.

* Cyzicus, one of the most powerful cities of ancient Greece, stood upon an island of the same name. It was originally united to Mysia, in Asia Minor, by two bridges; but Alexander the Great changed this mode of communication for a mole of earth, which subsequently accumulated to a considerable isthmus. Its buildings, coins, and laws were without parallel.

459. At Lurley-fels, on the banks of the Rhine, is a very famous natural echo. If in favourable weather a musket be fired on one side

Echo at Lurley-fels.

of the river, its report will be reflected from crag to crag till it dies gradually away, and, after seventeen repetitions, finally ceases.

Here P is the point whence the sound originates. After crossing the river it strikes the crag 1., is reflected to crag 2., then back to 3., then to 4., then to 5., &c. till it is ultimately lost in the direction of E.

460. Sir John Herschel has noticed a remarkable echo at the Menai bridge.* The blow of a hammer on one of the main piers, he says, is successively returned to each cross-beam which supports the roadway, and from the opposite pier 576 feet distant. Altogether the sound of the percussion is repeated twenty-eight times in five seconds.

Menai echo.

461. At the Palace of Simonetta, near Milan, in Italy, there is an echo which returns fifty or sixty times the report of a pistol. The palace has two wings; and when a pistol is fired from a window in one of the wings, the sound is reflected from a long dead wall in the other, and is heard at the *back* of the villa.

Echo of Simonetta.

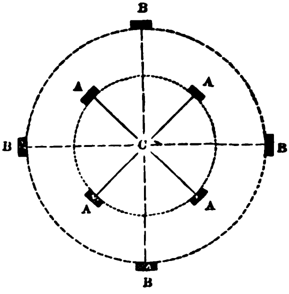
462. Echoes of this description are occasioned either by the echo itself being again reverberated

Cause of comp. echo.

* The Menai suspension-bridge is thrown across the strait which separates the Isle of Anglesey from Wales.

from other objects, or else by several obstacles so placed as to form supplementary ellipses or concentric circles.

463. In the latter case, the echo proceeding from the larger ellipse or circle will reach the ear later than that which proceeds from the less. Thus: Suppose A A A A to be four objects forming parts of the inner circle; and B B B B four objects situated in the circumference of the outer. Then a person



at C, the common centre, will hear his voice echoed first by the nearer obstacles marked A, and then by the objects (B) the more remote.

464. The interval between the first and the second echo will be equal, in this case, to the difference

Interval between the echoes.

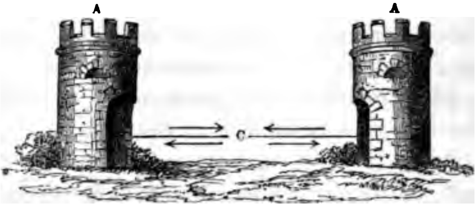
between the time required by sound to go up and down the longer radii C B, and that which suffices to reach the circumference of the *inner* circle, and return again to the centre.

465. Sometimes, however, a compound monosyllabic echo is merely the *echo of an echo*, as that of Lurley-fels, already described (459.). Of the same character also is the celebrated echo near Verdun, in France. About nine miles distant from this town there are two large towers, detached from a kind of hostel, or inn, and distant from each other 180 feet. One of these towers has a vaulted chamber of cleft stone, the other has a kind of vaulted vestibule. When a person stands in a direct line midway between these towers and pronounces a word in a pretty high key, he will hear it repeated twelve or thirteen times by the two towers alternately; in much the same way as the reflexions of objects are multiplied

Echo of an echo.

Echo of Verdun.

by two looking-glasses which face each other.

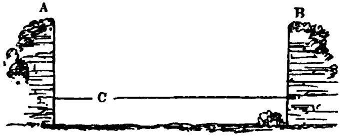


Let A and A be the two towers, C the person from whom the sound proceeds, placed exactly midway between them. He will first hear the direct sound echoed simultaneously from each tower. These two echoes, having reached C, will then fly respectively to the opposite tower, and be again reverberated to C. This will be repeated till the echoes are too feeble to be longer audible.

Interval between the echoes. 466. The time occupied between the first and second echo will be equal to the time which sound requires to go from one tower to the other.

467. If, however, the person from whom the sound proceeds be not placed exactly midway between two such towers, he will hear echoes which follow each other at unequal intervals. For example: He will

Unequal intervals.



hear, 1st, the echo from (A) the nearer object; 2ndly, the echo from (B) the object more remote; 3rdly, the echo proceeding from the object B, reverberated by A; and, 4thly, the echo from the object A reverberated by B. These echoes will be repeated, each time more feebly, till the sound-waves are exhausted and no longer audible.

In order that such an echo be possible, the distance from A to C must be at least 140 feet, and the distance of the further object 47 feet

more. It has been stated already that 140 feet must be allowed for a single echo (455. *note*); and the reason why the further object must be at least 47 feet more is this: the double of 47 is 94, and 94 is the *twelfth* part of 1120, the distance sound travels in a second. Experience shows that whenever two sounds succeed each other at an interval less than the *twelfth part* of a second, they constitute but one sensible impression; but when a greater length of time elapses between them, each of the two sounds is appreciable.

Each successive echo more feeble.

468. Each successive echo is more feeble than the preceding, because the sound-waves are in part *absorbed* by the reflecting surfaces; in part *dissipated* by the ascending and descending currents of air, by wind and shadows; and in part obliterated by the *resistance of the atmosphere* through which they pass.

SEC. II. § 2. COMPOUND POLYSYLLABIC ECHOES.

469. COMPOUND POLYSYLLABIC echoes repeat *two or more* syllables *two or more*

times. The following examples are sufficiently remarkable:—

470. At Andersbach, in Bohemia, is a forest of isolated rocks, which form a species of labyrinth. These rocks are situated in a plain three miles and a half in circumference. The rocks are peaked, but their heights vary considerably. The highest is about 200 feet above the level of the plain. Near the outer base of this gigantic group is a very remarkable echo, which repeats seven syllables thrice without confounding the sounds. The person who speaks must stand a short distance from the largest rock, pronounce his sentence in a low voice, and he will hear it rendered most faithfully. If, however, he move from what is called the *phonic point**, the loudest cry or even the report of a gun will produce no echo whatsoever.

Echo at Andersbach.

* The *phonic point* is the place where a person must place himself in order to elicit an echo. It is the point whence the direct sound originates.

Echo at Mettelli.

471. Gassendi*, the eminent philosopher and mathematician, speaks of an extraordinary echo in Rome at the sepulchre of Metella, the wife of Crassus. This echo, he assures us, was capable of repeating eight times correctly the first verse of Virgil's Æneid, which contains fifteen syllables.† It is obvious that the tomb must have been of great length, for it would require two seconds to pronounce articulately a whole hexameter line, and, therefore, for only one single repetition the reflecting surface must have been 1120 feet from the speaker (455. *note*).

Cause of compound polysyllabic echoes.

472. A compound polysyllabic echo can exist only under the following conditions: — First, there must be at least *two* reflecting surfaces; secondly, these surfaces must

* Peter Gassendi was born at Digne, in France, A. D. 1592, and died in 1655. He was one of the most eminent mathematicians that ever lived.

† *Arma virumque cano Trojâ qui primus ab oris.*

be at unequal distances; thirdly, the nearer must be at least 280 feet from the *phonic point;* and, fourthly, the more remote must be at least 47 feet further from the point whence the direct sound originates (467. *note*).

473. The more the reflecting surfaces are multiplied at unequal distances the more *frequent* will be the repetitions; and the greater the distance of any obstable the *more syllables* or notes will be correctly rendered. Number of repetitions.

SEC. III. THE HARMONIC ECHO.

474. The HARMONIC ECHO repeats in a different tone or key the direct sound. The harmonic is generally either the 3rd, 5th, or 10th of the tonic.

475. This phenomenon can be explained only on the hypothesis already stated (428.), that echo is not simply the direct sound reverberated, but a new sound elicited from Cause.

the echoing surface. In ordinary echoes the new sound succumbs to the tonic; but in harmonic echoes, the new vibrations being the more powerful, absorb and assimilate the direct sound.

The more powerful note buries or absorbs the more feeble. This may be illustrated by a flageolet or organ pipe. Two sounds are frequently uttered simultaneously by these instruments, one proceeding through the notch called the *mouth* of the pipe, and the other through its *foot*. The latter being the more powerful takes up the other to fortify its own note.

Another no less remarkable illustration is mentioned in No. 488.

476. On the river Nahe, near Bergen, and not far from Coblentz, is an echo, thus described by Barthius*:—It makes seventeen repetitions at unequal intervals. Sometimes the echo seems to approach the listener, sometimes to be retreating from him; sometimes it is very distinct, at others

Echo at Coblentz.

* Gaspard Barthius, a Prussian critic, commentator, and Latin poet, was born 1587, and died 1658.

extremely feeble; at one time it is heard at the right, and the next at the left; now in unison with the direct sound, and presently a 3rd, 5th or 10th of the fundamental. Occasionally it seems to combine two or more voices in harmony, but more frequently it resembles the voice of a single mimic.

Echo at Paisley.

477. At Paisley, in Scotland, there is a somewhat similar echo in the burying-place of Lord Paisley, Marquis of Abercorn. Musical notes rise softly, swell till the several echoes have reverberated the sound either in unison or harmony, and then die away in gentle cadence.

Echo at Killarney.

478. At the Lake of Killarney, in Ireland, is a very celebrated harmonic echo, which renders an excellent *second* to any simple air played on a bugle.

479. There was formerly, according to the authority of Dr. Birch*, an har-

* Dr. Thomas Birch was born in London 1705, and died 1765. He was a very voluminous, but in-

monic echo no less remarkable, seventeen miles above Glasgow, near a mansion called Rosneath. If a trumpeter played eight or ten notes, the echo would repeat them correctly a 3rd *lower*. After a short silence, another repetition was heard, still lower than the former; and after a similar pause the same notes were repeated a third time, in a lower key and feebler tone, but, nevertheless, with the same undeviating fidelity. This echo no longer exists.

Echo at Rosneath.

SEC. IV. THE ELLIPTICAL ECHO.

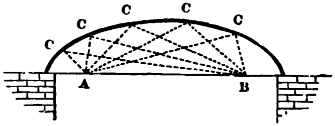
480. This is not, strictly speaking, an echo, but simply a *resonance*, inasmuch as the listener does not hear a sound repeated, but merely magnified. All "whispering galleries" may be classed under this category.

481. Let the subjoined woodcut

discriminate writer. His works, which are chiefly biographical, are exceedingly valuable for reference; and Dr. Johnson is repeatedly indebted to them.

represent the elliptical roof of some cathedral, crypt, cave, or vault. Let A and B be the two foci * of the ellipse; then a whisper proceeding from one focus (say A) will be heard at the other (B) with great accession of sound, because all the rays represented by the several lines A C will simultaneously converge there, and blend into a common sound equal to the sum of all the echoes. The following are good examples: —

Cause of elliptical echo.



482. The Whispering Gallery of St. Paul's is 140 yards in circumference, and situated just below the dome, which is 10 feet larger. A stone seat runs round the gallery along

St. Paul's Whisp. Gall.

* If in the figure the straight line bounded by the two walls represent the larger axis, or diameter of the elliptical roof, the *foci* are two points (A and B) towards its extremities, such that A C + C B = the entire line from wall to wall.

the front of the wall. On the side opposite the door by which strangers enter several yards of the seat are covered with matting, on which the visitors being seated, the man who shows the gallery whispers with his mouth near the wall, at the distance of 140 feet from the listeners, who hear the words in a loud voice seemingly close to their ear. The mere shutting of the door produces a sound like a peal of thunder rolling among mountains.

483. Persons situated in any other points except one of the foci are not sensible of these effects; because the sound-rays of one focus, being reflected, converge only at the opposite. Thus, in the woodcut attached to No. 481., two persons situated respectively at A and B might converse together in whispers without being heard by others either behind them or between these two points.

484. The vestibule, or, as it is called, "The Hall of Secrets" in the Obser-

vatory of Paris produces a similar effect, even in a more perfect manner, than St. Paul's Gallery. This hall is of an octagonal form, with cloister arches, which meet at angles corresponding to those formed by the sides of the building. The speaker applies his mouth very close to the wall at one of the angles, and the person situated at the opposite angle hears the slightest whisper.

Hall of Secrets.

485. In erecting the baptistry of the Church of Pisa, in Italy, the architect, Giovanni Pisano, disposed the cupola in such a manner that any noise from below is followed with a loud long double echo. Two persons whispering, and standing with their face near the wall, opposite to each other, can converse together without being overheard by the company between. This arises, of course, from the elliptical form of the cupola, each person being placed in the focus of the ellipse.

Baptistry at Pisa.

486. In the Cathedral of Gloucester there is an octagonal gallery above the eastern extremity of the choir, which extends from one end of the church to the other. If two persons, placed at the distance of seventy-five feet from each other, converse together in the softest whispers they can distinctly hear what is said.

Gloucester Cathedral.

487. At the Abbey Church of St. Alban's, in Hertfordshire, the ticking of a watch may be heard from one end of the edifice to the other.

St. Alban's Church.

To these numerous examples may be added the crypt of the Pantheon, and the large room in the "Conservatoire des Arts et Métiers," both in Paris.

488. The chief reason why CHANTING and INTONING the service was originally adopted in cathedrals is because the nearly monotonous voice blends in unison with the echo. A good "reader" will so time his syllables as to make each subsequent

Chanting and intoning.

one fall in with the echo of the preceding; in which case, although the syllables be altogether different, the returning echo will be arrested and merge itself in the louder sound; in consequence of which, much indistinctness of delivery will be prevented.

SEC. V. RESONANCE.

489. The walls, floor, and ceiling echo every sound which is produced in a room; but unless they are at least forty-seven feet distant the echoes combine with the direct sound, and increase by *resonance* its volume and length.

490. If the distance of a reflecting surface be less than forty-seven feet the echo will return in less time than the *twelfth of a second;* within which interval the ear is incapable of appreciating separate impressions.

491. It is of the utmost importance that buildings designed for large audi-

tories, such as theatres, churches, and lecture-rooms, should be so constructed that there may be no perceptible echo from the walls, but a sufficient resonance to give tone and volume to the speaker's voice. The best form for the interior of such rooms is that their length be about *two-thirds* greater than their breadth, in order that the sounds reflected from the side walls may mingle with the voice and strengthen it. The height should somewhat exceed the breadth, and the ceiling should be *coved*, that is, made in the shape of a coach-roof.

Construction of lecture-rooms.

492. If a lecture-room produce a distinct echo so as to render words confused and indistinct, or so as to annoy the audience with incessant murmur, drapery should be hung upon the walls. Venetian shutters are excellent preventatives of echo, especially when they are drawn forward. Matting, or any soft covering on the floor, serves to prevent the noise of feet

Echo prevented.

and to absorb reverberation. The transepts of a church are most inconvenient to a speaker, because of the repeated reflexions from these recesses, which greatly weaken the sound of his voice. The echo of the chancel may be obviated by erecting a concave parabolic surface behind the pulpit, so that the speaker may place himself in the focus.

Near Leeds, in Yorkshire, is a public lecture-room, where the echo was at one time quite distressing; but Venetian shutters have been placed against the windows, and whenever the audience is small, and the noise fatiguing the shutters are brought forward; when the room is full they are thrown back. The contrivance is found to answer admirably well.

Conclusion.

493. Resonance bears much the same relation to sound as colour does to light; the *timbre* or tone of a musical instrument, as well as its volume, are principally the effect of resonance. If it were not for resonance the thin length of wire or catgut of pianofortes, harps, and violins would produce notes too feeble to be heard in

a room of moderate dimensions. If it were not for resonance from the solid mass of the human head the sound of the voice would never rise beyond a whisper. It is from resonance that words uttered in a room are louder than in the open air. It is from resonance that wind instruments increase the sound created at their embouchure. If, on the other hand, the ear were more delicate, so as to be capable of appreciating every impulse, the confusion of sounds would be truly terrific. The racket of rolling carts would be distracting from the rattle of their innumerable echoes. Every sound in our houses, every word in our churches, would be repeated ten thousand times. We should hear the *direct* sound of one syllable mingled with the *reflexions* of another, and both recurring so frequently, that language would be a Babel of "confusion worse confounded." The voice of affection and of love, so tranquil, so soothing, and so

gentle, would be a clatter more painful than the gibbering of a stammerer. The song of the nightingale and thrush, the chirp of the cricket, the purring of the cat, and the baying of the yard-dog would be mouthed and mocked by every object around with a pertinacity more wearisome than the clack of a windmill, the pattering of the eaves-drop, or the monotonous creaking of a country sign. All the sounds which now delight the fancy and thrill the soul with their harmonious order and variety would resemble sonorous mists, and be no more intelligible to the ear than the separate oscillations of a vibrating harp-string, or the different spokes of a rapidly revolving wheel are appreciable by the eye. So perfect are all the works of God, that even their imperfections mark His consummate wisdom and unceasing love.

CHAPTER IX.

THE VOICE.

SEC. I. THE HUMAN VOICE.

494. All animals belonging to the class mammalia*, as well as birds and

* Mammalia; that is, all animals which suckle their young. Whales are an exception; they have no voice, although they belong to the class mam-

certain reptiles, have a voice. In many it is limited to a few uncouth screams, bellowings, cacklings, roarings, croakings, or other noises of a somewhat similar character. In singing birds it assumes a rich musical delicacy of great sweetness; and in the human species it has a perfection which marks the superiority of man to every creature put in subjection under him.

495. The vocal apparatus of man consists of three parts: —

I. The LUNGS, which supply the air, the generative *element* of vocal sounds;

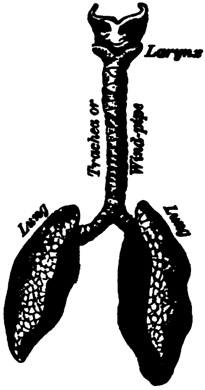
II. The LARYNX, the generative *organ* of vocal sounds;

III. The THROAT, MOUTH, and NOSE, which articulate, modify, and reinforce the voice.

496. The lungs, which occupy the cavity of the thorax, are two spongy

malia. Their larynx forms a pyramid, the pinnacle of which is situated in the nasal fosses; at each side of this pyramid is a passage for their food, surmounted by a round mucous membrane serving for an epiglottis. This arrangement enables them to swallow and spout forth water.

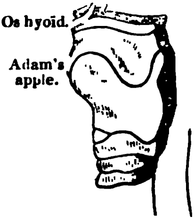
substances performing the office of respiration.



The windpipe is rooted in the lungs by two branches, and terminated at the upper extremity by a sort of cartilaginous box called the larynx.

The trachea receives the wind from the lungs, as the socket of an organ-pipe receives the blast of the bellows, and holds it in store till it passes into the vocal tube.

Profile of the Larynx.

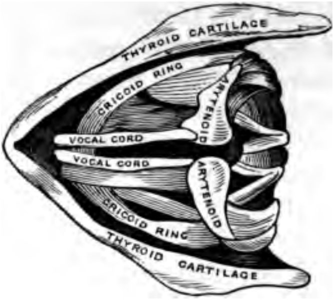


497. The larynx is situated in the cavity behind the tongue; it is in reality a continuation of the windpipe, and its profile forms that protuberance in the throat of a man called the *Adam's apple.*

Adam's apple.

498. The breath passes from the windpipe into the larynx **Glottis and vocal cords.**
through a small chink called the *glottis*, which is hedged in on both

Floor of the Larynx.



sides by what are termed the *vocal cords.*

In the woodcut the black part between the vocal cords represents the glottis.

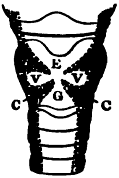
499. A little above the vocal cords the walls of the larynx curve **Ventricles of the larynx.**
into two small cells called *ventricles*, the roofs of which are

formed by two ligaments resembling the vocal cords.

500. The top of the larynx is surmounted by a lid, named the *epiglottis*, which shuts down when a person swallows, to prevent the food from entering into the windpipe, or "going the wrong way."

Epiglottis.

Inner Walls of the Larynx (represented by dotted lines).



E, epiglottis.
V V, ventricles.
C C, vocal cords.
G' lottis.

501. Vocal sounds are produced in the following manner: The vocal cords are first stretched by the insensible influence of the will. By the action of breathing, air is then forced rapidly from the lungs into the windpipe. When it reaches the narrow chink called the glottis, it impinges against the two vocal ligaments, by which it is impeded, and the shock sets them in vibration. The vibration of these ligaments is communicated to the air in the larynx; the sound is

Production of vocal sounds.

reinforced by the ventricles, and ultimately makes its way through the mouth and nostrils.

The resemblance between the vocal apparatus of man and an organ reed-pipe is sufficiently striking. The lungs are represented by bellows, the windpipe by the socket, the vocal cords by the languet, and the glottis by the mouth of the pipe through which the wind enters into the vocal tube.

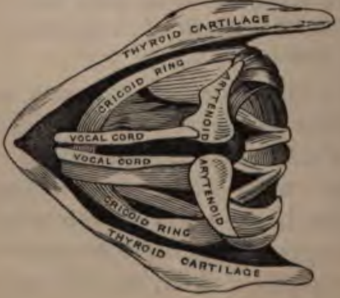
The resemblance, however, fails in the following respects: — The vocal cords of the human throat are situated at the *upper* end of the windpipe, whereas the languet of an organ-pipe is placed near the bottom of the tube. The vocal cords of man act like the reeds of a hautboy, but the languet of an organ like the steel tongues of a musical snuff-box. The chink of the glottis is situated between the two vocal ligaments, but the mouth of an organ-pipe has a different position.

502. The vocal ligaments are the seat of the voice; yet the cavities of the chest, throat, and mouth, together with their appendages and with the bony mass of the skull contribute greatly to its resonance agreeably to a principle of universal applica- Resonance of the voice.

tion, that *all substances in communication with a sonorous body enter into vibration with it, and increase its sound without changing its tone.* It is thus that the case of a drum and the body of a violin increase by resonance the volume of sound produced by these instruments.

That the vocal cords are really the seat of sound in the larynx will be manifest from the following considerations:—The power of uttering sounds is destroyed only by *cutting or paralysing the vocal ligaments.* All the other parts of the larynx may be destroyed without extinguishing the voice. Slit the upper liga-

Floor of the Larynx.



ments of the glottis, and the voice persists notwithstanding. Cut the *summit* of the arytenoïd cartilages, and the voice is affected only in quality and tone. It is the same of the epiglottis, if its muscles be cut or otherwise injured. But once destroy or paralyse the vocal cords by cutting the middle of the arytenoïds, or by slitting longitudinally the thyroïd, and the voice is irrecoverably destroyed.

§ 1. *Force of the Voice.*

503. The force or VOLUME of the VOICE depends chiefly on:

I. The *quantity* of air which is driven from the lungs into the windpipe;

II. The *energy* with which this current is directed; and

III. Certain physical conditions which vary not only in different individuals, but even in the same person at different times.

504. The general stature of an animal has no influence whatsoever on its vocal powers, inasmuch as the smallest animals have frequently the loudest voice: witness the braying of

an ass compared with the snort of a horse, elephant, or rhinoceros. Witness again the whistle of a blackbird and song of a lark, at least four times louder than the roaring of an angry lion*. But as the volume of the voice is dependent on the quantity of air driven into the larynx in a given time, those persons who are possessed of the largest chest are generally enabled to sustain their voice in its full strength longer than others.

Voice feeble after a meal.

After a full meal the voice is always feeble, because the capacity of the thorax or inward part of the chest is diminished†, and the supply of air from the lungs is less liberal. Other causes contribute to this enfeeblement of the voice after a meal;

* The voice of a lark elevated three miles high in the air may be distinctly heard, whereas neither the shout of a man nor the roar of a lion could be heard at the *sixth* part of that distance.

† The diaphragm, or partition which separates the stomach from the chest, being elevated after a full meal, diminishes the capacity of the thorax.

as, for instance, the inability of making such large inspirations as when digestion has advanced further,—the need which the muscles have of repose,—and their unwillingness at such a time for energetic action.

505. The size of the larynx and of its cavities or ventricles has, doubtless, a considerable influence on the force of the voice. When the swelling of the throat, called the *Adam's apple*, is very prominent, it generally indicates great vocal power inasmuch as it is consistent with a large development of the ventricles. On the other hand, the voice of children and women is more feeble than that of a man, because their larynx is considerably smaller.

Projecting Adam's apple.

The LION is remarkable for the extraordinary volume of his larynx, quite sufficient to account for the force of his roar, although, like all other animals of the same genus, he has no laryngean ventricles.

Lion.

The feeble screech of infants arises in a gre measure from there being no bony matter their head to increase by resonance the volur of their cry. As the ossification of the sk proceeds the voice becomes firmer and strong

Ass and hurleur.

506. In some animals of deafenir power of voice the larynx co tains other cells besides tl two ventricles: thus in the ASS and that group of monkeys common South America, called the sapaj hurleurs,* there are two membrano sacs attached to the upper rim† the larynx, communicating with i

* The sapajous, common in South America, ar group of monkeys, including some fifteen or sixte species, amongst which may be named the horn sapajou (*Cebus fatuellus*), the Capuchin or monk, t weeper (*Cebus apella*), and the stentor or hurle All the species have prehensile tails, climb well, a are very active; they are small in size, and grega ous. It is said that the cry of the hurleur at sunri sunset, and especially at the approach of a storm, m be heard at the distance of *a mile and a quarter*.

† This rim is technically called the os hyoïd (*fig*. 497.). The membrane which attaches it to t lower part of the larynx is dilated into two cells sacs, one on each side. These cells communicate, means of an aperture, with the bottom of the t ventricles of the larynx.

ventricles; and the hideous intensity of shriek which proceeds from these little animals is owing to the resonance of their voice in these cavities.

The HOG also has two lateral sacs, similar to those of the sapajou, and communicating with the ventricles, which are exceedingly small. The *grunt* of the hog is owing to the resonance of the voice in these two spacious cavities.

Hog.

The NEIGHING of HORSES is due to the rapid oscillations of a *thin semicircular membrane* situated just above the ligaments of the glottis. The ventricles of the horse are much smaller than those of the ass, and its vocal cords extremely short.

Neighing of horses.

507. The feebleness of the voice in old age is due to several concomitant causes: (1.) To the ossification of certain parts of the larynx; (2.) to the general feebleness of all muscular action; (3.) to the sinking-in or shrinking-up of the various parts of

Voice of the aged.

the body, in which the throat participates, as may be seen in the shrivelled neck of the aged; (4.) to the weakness or even difficulty of respiration, and probably to some minor causes, peculiar or accidental.

Voice obeys the will.

508. Lastly, the force of the voice is increased by opening fully the mouth, flattening the tongue, and causing the fleshy curtain* at the back of the mouth to contract so as to make the passage larger. All these conditions being either dependent on the will, or subject to "guiding emotions", or influenced by the automatic operation of passing ideas, man can lower his voice at one moment into a whisper, elevate it at another into a yell, pour into it the fervour of passion and declamation, or modulate it into the medium tone of social intercourse and general conversation.

* This curtain is called by anatomists *velum palati*. The uvula forms it into two arches; and the tonsils are situated at each side of it.

§ 2. *Pitch of the Voice.*

509. The gravity or shrillness of every sound depends always on the number of vibrations made in a given time. Rapid vibrations produce shrill or acute sounds; slower vibrations those that are more flat and grave (63.).

In stringed instruments a variety of pitch is effected by varying the length, thickness, and tension of the strings (64.); in wind instruments by varying the comparative force of the blast, the length of the tube, and the size both of the embouchure and of the pavilion (65.).

All these artifices, except perhaps the force of the breath, are effective in varying the pitch of the human voice. The length, thickness, and tension of the vocal cords may be varied at will by the mere play of the laryngean cartilages*; the chink of the glottis may

* The vocal ligaments may be rendered more or less tense by the movement of the *thyroïd cartilage* (*see fig.* 498.). They are *tightened* by the depression

be dilated or contracted by the same instrumentality.* By elevating or depressing the larynx the length of the vocal tube is altered; and by opening the mouth more or less, the size of the pavilion is varied.

510. Artists have availed themselves of these two last observations, insomuch that any one, on in-

Musicians painted.

of its front upon the *cricoïd* cartilage, and *slackened* by its elevation; as any one may easily ascertain by placing his finger against the little depression which may be readily felt exteriorly.

* The vocal cords may be brought into closer apposition by the movement of the *arytenoïd* cartilage; being made either to approximate more closely, or to recede in such a manner as to cause the chink of the glottis to assume the form of a narrow V. In a word, the

CRICO-ARYTENOIDEUS POSTICUS - CRICO-THYROIDEUS - - -	*open* the glottis.
CRICO-ARYTENOIDEUS LATERALIS - ARYTENOIDEUS TRANSVERSUS - THYRO-ARYTENOIDEUS - -	*close* the glottis.

The closure of the glottis forms part of the acts of *coughing* and *sneezing*. The object of the former action is to expel substances from the *throat* which are a source of irritation there; the object of sneezing is to expel from the *nostrils* that which produces an irritation in this air-passage.

specting a picture of vocal musicians, may recognise in a moment the *rôle* they are each represented to take. The open mouth, projecting chin, and elevated eye, cannot fail to represent an *alto* or treble singer. The half-closed mouth, forehead brought forward, neck contracted, chin lowered and forced into the throat, bespeak a low bass. Whereas, when we see the superior lip curled upwards, the head thrown back, the eyes contracted, and all the muscles of the face rigid and overstrained, we are certain that the artist designs to depict a falsetto singer labouring to contract the muscles of his throat and to make the upper part of the vocal tube as rigid as possible.

For bass sounds the Adam's apple is drawn down and dilated by the play of certain muscles, and thus the vocal tube is shortened while its aperture is enlarged. The epiglottis is also partially closed by the retraction and depression of the tongue.

The reverse takes place for treble sounds. The larynx is elevated, and the aperture of

the glottis lessened; in consequence of which, the air passes through it with greater force, and its vibrations become more rapid.

Falsetto voice.

511. The FALSETTO or head-voice seems to be produced in a manner resembling the sound of a flute. The chink of the glottis is nearly closed, as the mouth-hole of a flute by the lower lip of the player. The air from the windpipe strikes against the rigid edge of the vocal ligaments, is thrown into vibration, and communicates its motion to the air in the throat and mouth. In order to contract the passage of the voice, the uvula is shortened and raised, the tongue made convex and strongly contracted at the roots, the tonsils dilated, and the cavity of the throat rendered as small as possible.

Children's and women's voices.

512. The voice of CHILDREN and WOMEN is considerably higher than that of men, because the chink of the glottis* is consider-

* The chink of the glottis, in women and children,

ably smaller. At puberty the larynx of boys begins to enlarge, and often within twelve months acquires a dimension double its former size. During this period the voice is harsh and uncertain, now squeaking with childish treble, now lapsing into manly bass, because the vocal ligaments and all the parts of the larynx are deranged in consequence of their rapid development and the incipient ossification of the cartilages. During this period a boy should absolutely abstain from singing for at least six months. He may then in some instances resume it in moderation; but the voice rarely assumes its full development within two years, and is sometimes as many as seven before it is fully settled.

513. The larynx of WOMEN enlarges very slowly, except in some extraordinary cases, where they **Woman's voice rarely breaks.**

is about six lines, whereas in men it is eleven lines. The ventricles of the larynx are also smaller in the former case than in the latter.

acquire a *masculine* tone of voice; this, however, is of rare occurrence, and their voice much more frequently preserves its youthful delicacy and clearness after they have attained their full stature, and in some instances even to good old age.

Some girls experience a slight change of voice; the *alto* gaining a note or two above its former compass, and the *soprano* sometimes dropping into a contralto.

514. We have already remarked that the voices of women and children are much higher than those of men; so that when a man and woman sing the same part, the woman pitches her voice an octave higher than the man. The great division, therefore, of voices is into *male* and *female*. Both these are subdivided into three classes: the highest pitch of the male voice being called *tenor*, the medium *barytone*, and the lowest *bass*. The highest pitch of female voices is termed *treble* or alto,

Voices classified.

the medium *soprano*, and the lowest *contralto*.

Persons possessed of each of these qualities of voice have pretty nearly the same compass, which averages twelve or fourteen notes in men, and somewhat more in women; so that the entire range of the human voice, from the deepest bass to the highest treble, may be estimated at twenty-six notes, the lowest being F below G gamut in the bass, and the highest extending to C in alt.

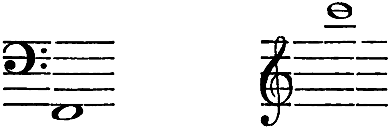


Table of Men's Voices.

1st octave. **2nd octave.** **3rd octave.** **4th oct.**

F G A B, C D E F G A B, C D E F G A B, C

D E E P B A S S.

B A R Y T O N E.

T E N O R.

Table of Women's Voices.

2nd octave. 3rd octave. 4th octave. alto.

F G A B, C D E F G A B, C D E F G A B, C

C O N T R A L T O.

S O P R A N O.

TREBLE or ALTO.

515. No animal has so large a compass of successive notes as man; SINGING BIRDS approach the nearest, but few of these have more than three-quarters of an octave at their command.

Singing birds.

The chirp of some birds begins on their fundamental note, and starts abruptly into a double fifth, but the intermediate notes are very imperfectly supplied.

516. Singing birds are enabled to vary their notes in consequence of the extraordinary flexibility of their windpipe, which they can shorten or lengthen at will. No other animal has the same power. Thus men and quadrupeds modify their voices by extending or shortening their mouth and chin, by

altering the position of their lips, and by a certain play of the throat. As all these parts in the human animal are very flexible, he is able to execute a vast number of modifications; whereas horses, oxen, dogs, cats, and numerous other quadrupeds whose mouth, lower jaw, lips, and neck have but little play are exceedingly limited in their vocal powers.

§ 3. *Timbre of the Voice.*

517. The *timbre* or individual tone of no two voices is exactly alike, hence arises the facility of recognising acquaintances by the sound of their voice. In musical instruments the timbre depends on the material employed in their construction (109.), and the peculiar quality of the human voice also depends in a great measure on the thickness and consistency of the laryngean cartilages, and on certain physical conditions of the larynx, palate, teeth,

nostrils, and other parts more or less connected with the organs of speech.

The timbre of the voice is also considerably affected by the mouth: thus when a person sings with his mouth shut the tone of his voice is completely changed.

Delicacy of woman's voice.

518. The voice of women and children is more sweet and delicate than that of men, because their larynx and its cartilages are more supple. As persons advance in life these parts ossify, and acquire a rigidity which gives depth and roughness to their tone. The same is affected sometimes by certain habits, as when a person sings or speaks "through the nose," causing the voice to ring in the nasal fossæ instead of passing freely through the open mouth.

Voice affected by disease.

519. In all cases of INFLAMMATION which has its seat in the larynx the voice is considerably altered, becoming hoarse, feeble, and sometimes discordant. The hoarseness increases as the disease grows more

inveterate, till ultimately the voice is entirely extinguished.

When the windpipe only is inflamed the voice undergoes but little modification; if the disease be situated in the gullet, the hoarseness is very marked, articulation becomes difficult, and not unfrequently impossible.

Even defective teeth and chapped lips exercise an influence on the tone of the voice. The same may be said of fatigue and ill health generally, distress of mind, or any violent emotion; insomuch that the ear can discriminate in a moment, whether a person be well or ill, happy or vexed, weary or lively, sad or gay, tranquil or excited.

§ 4. *Speaking.*

520. Vocal sounds and articulate lauguage are two things entirely different. The former may be produced in great perfection where there is no capability for the latter.

That physical organisation should have the power to produce sounds is no more remarkable than that a rose or violet should exhale a perfume. Even inanimate nature has this power; witness the purling stream, the impetuous waterfall, and the roaring ocean; witness the tittering of autumnal leaves, the whistling wind, and the pattering rain. Sound seems as essential to matter in motion as colour to light; but that any organic apparatus should be able to convey from one body to another abstract ideas—that any function of mere matter should have the power to interpret the emotions of mind—that wishes, thoughts, imagination, hope, fear, metaphysical subtlety, and the dreamy ideal, —that these should be able, by the mere play of a couple of ligaments and the aid of a few muscles, to be reduced to tangible sounds, this is so astounding, so utterly "past understanding" that no penetration of thought could have conceived it pos-

sible had it not been constantly familiar to us.

521. Vocal sounds are produced by the larynx, but the modifications of them, by which language is formed, are effected for the most part in the oral cavity. They may be divided into two classes, *vowels* and *consonants*. The former dependent on the voice alone, without the interference of the tongue, lips, teeth, or palate. The latter produced by the interruption of the voice in its passage between the larynx and the lips.

Those consonants which are produced by an interruption of the breath in the throat are called *gutterals;* those which are articulated by the tip of the tongue *linguals;* if the vocal sound receives its impression from the lips the result is a *labial;* if from the teeth a *dental*.

522. Singing and speaking aloud is conducive to health *after digestion*, but should be avoided *before*. A large and strong muscle,

When speaking is healthy.

which acts like a pair of bellows, in admitting air to the lungs or in repelling it, is connected with the lower part of the breast-bone and the ends of the last rib. The action of this muscle is so powerful on the upper region of the abdomen, that it forces the stomach and viscera to make their distribution; a muscular action, very conducive to health after digestion has somewhat advanced, but extremely prejudicial when the food is in a crude and undigested state.

§ 5. *Ventriloquism.*

523. This misnomer arose from the notion, formerly entertained, that ventriloquists are accustomed to fetch their voice from the stomach and not from the larynx; this, however, is not correct. Ventriloquism is a vocal "sleight of hand," in which the artist practises on our habits to deceive our senses. Being a good mimic, the ventriloquist can imitate retiring or advancing sounds,

those at a distance, those in another room, or those of different speakers. He practises on our ears by light and shade as a painter practises on our eyes. There is, however, a limit to both arts, which can never be overpassed. The hypothetical sounds of a ventriloquist must always be represented to proceed from some person or thing *before* the auditors and not *behind* them, supposing that they face the operator. If the ventriloquist be placed to the *south* of his company, it would be useless for him to attempt to cause any sound to proceed from an object *north* of his audience, or even from the direct east or west; the dullest ear can distinguish the direction of sound with sufficient accuracy to prevent such deception; but there is an angle within which the ear cannot distinguish a difference in the direction of sound. Thus when a bird is singing in a tree or at a window, it is very rarely the case that the eye can in-

stantly hit upon the exact spot where the bird is perched. If the sound proceed from the left side no one would seek the object on the right; but many would look a little too high, or a little too low, or a little too obliquely, before the object of search would be discovered. This "angle of uncertainty" is the range of deception, and the ventriloquist must confine his mimicry to it, or he cannot deceive.

524. A tone of voice somewhat resembling that of the ventriloquist may be elicited by *drawing-in* the breath in the act of speaking instead of forcing it out. This peculiarity of tone arises from the feebleness of the inspiration and the extreme tension given by the effort to the vocal organs. Both these causes operate in ventriloquism also, and account for the want of volume in this sort of speech. Its muffled character may be easily explained, inasmuch as the ventriloquist speaks with his mouth nearly closed, and directs

the current of his voice against the curtain of his throat. The articulation is imperfect, because the organs of pronunciation are distressed by unnatural action.

The witch of Endor, according to the authority of the Septuagint, practised upon Saul by ventriloquism; by the same vocal jugglery the ancient priests made their oracles utter their responses at one time from the innermost penetralia of their temples, at another from caverns underground, and sometimes their voice seemed to issue from a tree or from the clouds.

St. Giles, according to the traditions of the Romish church, employed the art of ventriloquism as a "terror to evil-doers, and a praise to those that did well;" yet the Abbé Fiard, following the example of the Archbishop Eustache, has lately published an elaborate treatise to prove that all ventriloquists are *possessed!!* It is certain they were subject to capital punishment so low down as the sixteenth century, about which time Roland du Vernois was condemned and burnt to death.

SEC. II. THE VOICE OF BIRDS.

525. The vocal apparatus of birds differs considerably from that of man and other mammalia. Their windpipe con-

tains a larynx at the top and another at the bottom of the tube, and instead of having only one glottis it has three.

Upper larynx.

526. The UPPER LARYNX of a bird is situated at the base of the tongue; its glottis is a longitudinal slit resembling a small button-hole, the edges of which are perfectly rigid. There are neither ventricles, vocal cords, nor epiglottis; but in some instances a cartilage covers the laryngean aperture in the act of swallowing, to prevent the food from falling into the windpipe.*

* In birds the epiglottis is supplied by *papillæ* or

The form of the windpipe, in singing-birds, and in some birds of prey, &c., is that of a *cylinder*.

In turkeys, herons, bitterns, cormorants, and some few others it is *conical*, the largest part being nearest the lungs.

In harles, drakes, &c., it swells in the middle, and is contracted at the two extremes.

527. At the bottom of the trachea is another larynx, communicating with a glottis situated at the top of each¶ branch (*fig.* 526.). In singing birds this lower larynx is much more complex than in others, being separated at the lower extremity by several muscular rings, the last two of which seem to amalgamate so as to form a bony drum. This drum communicates from below with a glottis situated at the top of each branch, and provided with vocal ligaments. Lower larynx.

The king of the vultures, the golden vulture, and one or two other birds, have no lower larynx.

kinds of fleshy scales all round the chink of the upper glottis. These papillæ open upwards when a bird swallows, and effectually arrest the passage of food into the windpipe.

In some birds the larynx has *no* muscl connected with the vocal apparatus, as in swan geese, and ducks. In others it is furnished wi a *single* pair, as in the eagle, falcon, buzzar sparrow-hawk, goshawk, brown vulture, &c.; t these may be added the kingfisher, heron, bi tern, cuckoo, and owl. All these birds have voice monotonous, and without modulations.

In some other birds the larynx is provid with *three* pairs of muscles; as in the perroqu and parrot.

In singing-birds it has generally *five* pair Such is the case with the nightingale, tomti blackbird, thrush, goldfinch, lark, linnet, canar swallow, sparrow, starling, jay, pie, and crow.

528. As the vocal cords of birds a situated at the bottom of the windpipe, the air from the lungs must traverse the whole leng of their trachea in a state of vibratio whereas in the human species and all other mammalia, the vocal lig ments being at the top of the windpip the air does not enter into vibrati till it has left the trachea for t larynx.

Voice of birds.

529. The sounds made by birds a

produced in a manner precisely analogous to that of the *labial whistle* (360.). A current of air periodically variable is forced from their lungs through the narrow chinks in each branch of the lower larynx. The impulsion of this rapid current against the air which it encounters at these two points produces sonorous vibrations, which are increased and reinforced in their passage through the windpipe.

530. The fundamental note of different birds varies in pitch, owing to the different lengths of their respective windpipes; the rigidity of their tracheal membranes; and the size of their upper glottis. It is probable, however, that all birds sing in the same key (G, with a flat third), and that this is the reason why in a grove, the ear is never pained with discordant sounds, though a thousand birds may be singing at one and the same time a thousand different songs.

Pitch, and key.

The fundamental note of the thrush and bar cock is A, of owls B, of Bantam cocks C, woodlarks F, of nightingales G, &c. But t pitch is very considerably higher than that a fife, or of any other musical instrument i vented by man.

531. The trachea of birds is flexible, that they can lengthen shorten it at pleasure, in order to pr duce different notes. B) *elevating* lengthening the trachea, the chink the superior glottis is co ıtracted, aı the tension of the windpipe considerab increased. By *depressing* the trache the upper glottis makes a larger ape ture, the windpipe is relaxed, and tl note produced is more grave.

Singing birds whose lower larynx is furnish with five pairs of muscles can vary the length their windpipe by the mere play of the differe muscles without moving their head.

532. Of all birds the NIGHTINGA: is the best singer; it is t standard of all the warblers the grove, and other birds are classifi

Nightingale.

in merit as they are able to execute one or more of its musical refrains. In April the nightingale sings with great diffidence, indecision, and feebleness, as if feeling its way, assaying its powers, and preparing its future ditties; soon, however, it acquires more confidence, and grows more ardent, till in May it bursts into full song, and nothing can exceed the grace, the good taste, the inimitable variety, and faultless execution of its strains, — now gurgling like a purling stream, now dropping as honey from a rock, now lancing forth like a rocket with resistless volubility and astounding brilliancy, now subsiding into a still small voice like a half-articulate wail. Sometimes plaintive as a turtle, at others precipitate and rapid as fire among thorns; then smooth and steady as a fertilising stream, and anon trilling with the most artistic skill, yet without art; surprisingly elaborate, yet so full of soul as not only to enchant the ear

with its execution, but also to win the heart with its pathos.

These different refrains are not strung together pell mell one after another, till the creature is fatigued, but are most gracefully interrupted by intervals of silence, which greatly add to their effect. The ear has listened to some exquisite cadence, is charmed, is satisfied, — wishes to drink in and revel on the draught, — it is allowed time to do so, to meditate, to reflect; but no sooner does desire revive again, than a new warble commences, if possible, more pure, more articulate, more brilliant, more perfect than the last, — more varied in its turns, more marked in its transitions, more excursive in its freedom, more extraordinary in its execution. With all this wonderful power and beauty of song, the nightingale does not possess a compass of voice exceeding a single octave. Not that it cannot touch upon the *eighth above* of any particular note, this it will often

do for effect; but that its song, properly so called, its warble, and its trills, are contained within a single tetrachord.*

The "mode" of a nightingale consists of much smaller intervals than those of our chromatic scale; some judges affirm it to be in *quarter tones*. Be this as it may, it is certain that many of its intervals are less than semitones.

533. The SKY-LARK and LINNET come next in variety of tones and excellency of execution; but their songs are less melodious, their changes less numerous, their notes fewer and less sustained. After these two, no other bird can approximate in melody and execution to the great model, and some, like the cuckoo, have no more than a fundamental note and its flat third. Lark. Linnet.

* Tetrachord, *i. e.* the successive notes of any one octave.

534. TABLE SHOWING THE RELATIVE MERITS OF THE MOST COMMON OF SINGING BIRDS.

(In this Table 20 is assumed as the point of perfection.)

	Relative compass.	Relative excellency of tone.	Relative Duration of song.	Relative execution.
Nightingale -	19	19	19	19
Skylark - -	18	9	18	18
Linnet - -	16	15	16	18
Blackcap -	14	13	14	14
Titlark - -	12	12	12	12
Robin - -	12	11	12	12
Goldfinch -	12	9	12	12
Woodlark -	12	13	10	8
Chaffinch -	8	7	8	8
Greenfinch -	4	4	4	6
Thrush - -	4	4	4	4
Wren - -	4	4	4	4
Hedge-sparrow -	4	3	6	4
Blackbird -	2	13	12	2

The nightingale has sixteen different methods of beginning and closing its refrains, the intermediate notes being arranged with endless variety: and it will sustain its song without once pausing for the space of twenty seconds.

The skylark comes next, not only in variety of changes and in execution, but also in the length of time which it sustains its song.

No other bird can execute more than four or five changes, or can sustain its song above a few seconds.

535. Certain birds, as the drake and harle, have two small cavities situated near the upper orifice of their windpipe, and the peculiar hoarseness of their cry is due to the resonance of their voice in these little cells. Drake.

536. All singing birds have the power of imitation so strongly developed, that their song is strongly characterised by their associates; but those birds which mimic the articulate sounds of the human voice, as the parrot, raven, mocking-bird, and so on, employ the *tongue* to execute their imitations. Mocking-birds.

SEC. III. VOICE OF REPTILES.

537. Very many REPTILES* have *no* vocal apparatus proper to engender

* Reptiles, according to Cuvier, are divided into four orders: (1.) Chelonia, or *tortoises*; (2.) Sauria, or *lizards*; (3.) Ophidia, or *serpents*; and (4.) Batrachia, or *frogs*. The first and last of these orders are for the most part amphibious; lizards and serpents live chiefly on the land.

sounds; and even those which have a voice have only *one larynx*, which rather resembles the upper glottis of birds than the complex vocal apparatus of man, being for the most part little else than three pieces of cartilage, with a chink or glottis, without either ventricles or vocal cords.*

538. The larynx of male FROGS and TOADS is the most perfect of all the reptile tribe. In consists of a delicate ring and two fine transversal cartilages on each side, terminated at each extremity in a small cell or cavity. At the lower lip of these cells is a little membranous tongue, which serves the purpose of vocal cords. Just above these tongues are two other cavities, which may be called the ventricles of their larynx. Frogs and toads have lungs, but no windpipe.

Toads and frogs.

* Some amphibious reptiles furnished with gills, as the siren (a kind of frog found in North America) and the axolote, a Mexican lizard, have the rudiments of a cartilaginous larynx.

539. These animals are enabled to inflate themselves, owing to two small membranous sacs situated on each side of their lower jaw, and communicating with their mouth. These sacs, which are filled with air when the creatures croak, serve by resonance to increase their voice, and enable them to utter cries under water.

Inflation of toads.

540. Next to toads CROCODILES have a larynx better developed than other reptiles. They have the rudiments of vocal ligaments, and the power of contracting their glottis at will. Young crocodiles mew like kittens, but n maturity low like sea-calves.

Crocodile.

541. LIZARDS have no vocal liga-ıents, yet several different ›rts of this order of reptiles ›n utter cries by a voluntary move-ent of the glottis; and one particular ecies, called the *gecko* *, has a voice very extraordinary capacity.

Lizard.

The gecko is a nocturnal lizard. Its head is feet short, toes of nearly equal length and re-

542. The TORTOISE can utter a fee
Tortoise. cry when it is tormented. T
glottis of this animal is cove
with a membrane which serves the pl
of an epiglottis, and the faint sounc
utters is due to this arrangement.

543. SERPENTS have no real voi
Serpent. Their *hissing*, which is produ
by the rapid passage of
through the narrow fissure of th
glottis, not meriting the name.

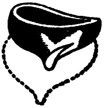
544. The rattle of the RATTLE-SNA
Rattle-snake. is due to an apparatus situa
at the end of its tail. This a
paratus consists of a certain number of hollow, hard, dry bones, as brittle as glass, very sonorous, and fitting loosely together. When the creature moves its tail, these loose bones hit against each other and resound. The rattles are formed when

A rattle of five bones.

sembling rose-leaves in form. Its tail is not lon
nor has it a dorsal crest.

the serpent casts its skin, the epidermis being then rolled into a knot at the end of the tail; and every time the slough is ejected another rattle is added to the number.

A single rattle.



The epidermis is a thin membrane which covers the skin.

545. It has been often questioned whether FISHES have the power of producing vocal sounds or not? It is certain that the *roach* and *trout* can utter a sort of feeble cry, although the exact position of their vocal apparatus is by no means certain. It is probable that the sound referred to is the result of *intestinal respiration* resembling a sigh; but nothing positive can be stated on this curious phenomenon till physiologists have been enabled more fully to investigate the matter.

Fishes.

SEC. IV. SOUND PRODUCED BY INSECT

546. INSECTS have *no voice*, becau they have no larynx. Their hummir buzzing, droning, or chirping, is pı duced either by the flutter of th wings or by the friction of some pa of their teguments against another.

547. The noise of several of the i sect tribe answers no other purpo than to indicate their whereabouts animals in search of them as lawf prey. The stridulation of others, for example, of the death-watch, cada, and grasshopper, serves to attra the two sexes to each other. Some, the bee and white ant, seem to coı municate their wishes by their differe noises, and even to express by the means different sensitive emotions.

548. The HUMMING of the BEE appea to be due to vibrations ger rated in the thorax by the rap contraction of the muscles of its win in movement.

Bee.

549. Every one acquainted with these interesting insects is well aware that their humming varies considerably according to circumstances.

During the ordinary labour of the hive a certain murmur prevails, which conveys to the swarm the commands or intelligences necessary for the work in hand. This busy hum is entirely changed if the bees are disturbed, assuming a sharp, angry, impatient character, especially if some of the community have suffered death. The buzz is exceedingly plaintive when the queen-bee is taken away; but bright, quick, and joyous as soon as she is restored.

550. The soldier termite, or WHITE ANT, makes a sound somewhat sharper and quicker than the ticking of a watch, by striking some hard substance with its mandible or upper jaw. The object of this notice is to urge the common ants, or labourers, to increased exertion when the work goes on too tardily.

Termite or white ant.

551. A similar noise is made in a similar way by an insect called *anobium*, or the DEATH-WATCH —a small beetle which burrows in old wood. This tapping is a call to the female. After it has been made the insect waits to hear if it be answered; if not, he changes his position and taps again. Any one, by imitating the noise with his finger, may easily deceive the creature, and induce it into a dialogue of considerable length.

Death-watch.

552. The CUCULLUS, or *notoxus*, an insect very destructive to granaries, produces its stridor or tapping noise by striking the extremity of its body against any hard substance on which it may happen to light.

Cucullus.

55 The sounds of the cicada and grasshopper also refer to sexual desires.

The male CICADA, or tree-hopper, has an apparatus of sound very remarkable. It occupies the first segment of the abdomen, and consists

Cicada.

of a thin membrane tightly stretched across this cavity and confined in two little horny grooves shaped like bows. Two muscles are attached to this frame, one of which is exceedingly small and serves to augment the tension of the membrane; the other, much stronger, serves to relax it. The note of the insect is produced by an alternate tightening and loosening of this drum-head by the action of the two opposing bundles of muscular fibres attached to this frame. The sound thus engendered is made more intense by an apparatus of reinforcement running the whole length of the body. A great cavity occupies the thorax, and another the abdomen. The two communicate with each other by means of a triangular space left between two muscles. The sonorous vibrations produced at the abdomen circulate through this instrument, and make their way out through the last segment of the thorax. This curious

apparatus is fully sufficient to account for the clear loud cry of this insect. In some species the "song" may be heard to a considerable distance; that of the *cicada of Brazil* to the enormous distance of a mile.

Grass-hopper.

554. Male GRASSHOPPERS alone are vocal; and their chirp is produced by rubbing the edge of their wing-cases against the inner surface of their hinder thighs, which is covered with a scaly armour. The note of one male is seldom heard without being returned by another; and the two insect warriors, after many mutual insults, attack each other with great fury, the female being always the reward of victory; for no sooner is the combat over than the conqueror seizes his prize with his teeth behind her neck, and keeps her prisoner at pleasure.

Cricket.

555. The house CRICKET has a somewhat different arrangement—its merry "hearth-song" being

produced by the attrition of the anterior pair of wings against each other. One of the wing-cases has its edge notched, or indented like a file or delicate saw, and this shard is made to pass over the shard, or sheath, of the opposite wing. The sound thus produced is augmented by resonance from a certain part of the wings, surrounded by strong nervures*, which stretch the thin membranes so tightly, that they act like drum-heads.

The cricket is a very chilly insect, seldom leaving the warm fireside, and, if undisturbed, will fearlessly hop from its retreat to chirrup at the blaze in the chimney. It may, however, easily be surprised by lighting a candle suddenly, when it will be dazzled, and, being unable to find its way home, may easily be caught. It may also be frightened away by any loud noises.

556. The ravenous LOCUST produces its formidable noise in the act of mastication. This insect is furnished with very powerful jaws, Locust.

* Nervures are horny tubes for expanding the wings of insects and keeping them tense.

"whose teeth are as the teeth of a lion, and their cheek-teeth the cheek-teeth of a great lion." When an army of these destructive insects, some three miles long and several yards deep, "lays waste a field, barking the fig-trees, making them bare, and the branches thereof white" a noise is produced which the prophet Joel compares to "the noise of chariots on the tops of the mountains, or to the noise of a flame of fire that devoureth the stubble." This fearful tumult is the result of the simultaneous action of many millions of powerful jaws, and the ripping off of the bark, or tearing to atoms the fibres of the trees which the swarm is ravenously devouring.

557. The droning of the "sharded BEETLE" arises from the friction of the parts between its *prothorax* and *mesothorax*; that is, between the first segment of the thorax and the part from which spring its anterior wings and middle pair of legs.

Beetle.

The thorax of insects is the second segment, or part between their head and their abdomen. The part of the thorax nearest the head is termed the *prothorax;* the middle part constitutes the mesothorax.

558. The shrill noise of some other insects of this species results from the friction of their abdomen against the inner face of their wing-cases.

559. The buzzing of a FLY depends on the rapid escape of air, du- Fly.
ring the muscular effort of flying, through extremely minute apertures of their body communicating with their windpipe. These external organs of respiration are technically called *stigmata.*

560. The shrill "trumpet" of the GNAT is simply the effect of vi- Gnat.
brations communicated to the air by the agitation of its wings. So rapid is this movement, that it impresses the air with 15,000 vibrations in a single second.

561. So wonderful, so complex, so

curious, so diversified, are all the wo
of God! "In wisdom hath He ma
them all!" Ask of the burning s
rolling through fields of air,—ask of t
placid moon sleeping on the bank,
ask of the host of heaven, the wate
and the earth,—and you shall present
hear not alone the "shout of the so
of God," and the "song of the mo
ing stars," but a universal voice, risi
like incense from every corner of t
universe, and quiring, in one vast acco
"In wisdom hath He made us all
That wisdom speaks aloud not only
the vast and mighty, but also in t
insignificant and minute. Not only
the thundering storm, and hercule
waterfall and irresistible whirlwi
and riving earthquake; but also in t
tiny insect of a day, born with t
morning light and dying with the s
ting sun. Not only in the innum
able worlds driven with his guiding ha
through fields of space; but also in t
infinitesimal machinery of the chirr

of the cricket or cicada. Amazing in diversity no less than in skill! Infinite in ingenuity no less than in propriety. Now shaking the " wilderness of Cadés and breaking the cedars of Lebanon," and anon rousing the dull ear of night with the ticking of an insect whose life is spent in making the tour of a rotten plank. Now roaring in the hurly burly of a volcano, and anon humming from the thorax of a bee, or buzzing in the stigmata of a fly. Now heard in the overpowering ocean, now in the harmony of the grove, now in the voice of man, and anon in the small whisper of the tiny midge calling to the devouring bat, or in the grasshopper chanting his shrill love song to his female companion. Such and far more wonderful is the wisdom of Omniscience!

> " His works, ...
> E'en in the depth of solitary woods,
> By human foot untrod, proclaim his power,
> And to the quire celestial Him resound,
> Th' Eternal Cause, Support, and End of all."
>
> THOMSON.

CHAPTER X.

THE ORGANS OF HEARING.

562. PROBABLY all animals posses of sensibility have the power of he ing, although in some of the infer classes the organs for this purpose extremely rudimentary, and in oth the anatomist can trace no apparat resembling the ear of the hum species: thus WORMS have no ears,

[redacted]

they seem to manifest at times an alarm at loud noises, either because their sense of hearing is somehow connected with their sense of feeling, or else because loud noises shake the air and earth, and their sensitive body warns them to flee from apprehended danger.

GRASSHOPPERS, CRICKETS, and CICADA have no apparatus for hearing resembling that of vertebrated * animals, yet is it generally supposed that their chirp, like the song of birds, serves to attract the two sexes to each other.

Bees, again, have no ears, yet common consent gives them the credit of hearing; and the tinkling made during their time of flight is designed for no other purpose than to prevent their hearing the hum of their exiled queen.

* Vertebrated animals are those which have a backbone, as man, and all quadrupeds, birds, reptiles, and fishes. Insects and molluscs have no backbone, and are therefore termed invertebrated.

563. There seems to be a relatic between the development of tl vocal and of the hearing app ratus of each species of anima Thus man, whose voice is the most pe fect of all living creatures, has at tl same time the most perfect organisatio for hearing. Birds, whose song is d signed to delight their kind, come ne to the mammalia in this respect. Re tiles possessed of a voice, as toads, cr codiles, and lizards, have the organs the ear more fully developed tha fishes*; whereas zoophites, which hav no voice whatsoever are also utterl insensible of sounds.

Relation between the voice and ear.

564. In the mammalia, and esp cially in the human species, th auditory apparatus is most wor derfully contrived. It consists of thre parts, called the outer, middle, an inner ear. The office of the first is t collect the rays of sound and refle

Ear of mammalia.

* For the hearing apparatus of fishes, *see* No. 13 with the *note*.

[redacted]

them inwards; the office of the last is to impress the acoustic nerve; and the office of the middle ear is to connect together the other two, and to modify the general apparatus for different degrees of sound.

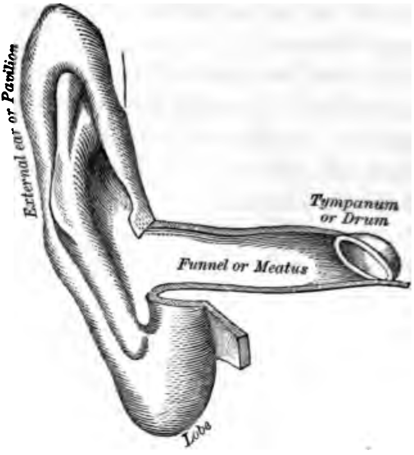
In order to make the subject intelligible to the general reader, it will be advisable to direct attention to each respective part of the human ear in a separate paragraph.

SEC. I. § 1. *The Outer Ear of the Human Species.*

565. The OUTER ear may be compared to an ear-trumpet. It consists essentially of two parts; **Meātus of the ear.** the external cartilage, called the *wing* of the ear, and its funnel or *meātus*.

566. The dimension of the funnel gradually decreases as it recedes from the pavilion; and its inner orifice is covered with a delicate membrane, stretched over it like the parchment head of a tambourine. **Drum of the ear.**

This membrane, called the *tympănu* or drum of the ear, is very elasti and whenever the sound-waves of t



air strike against it, their shock sufficient to impart to it reciproc vibrations.

The *membrana tympani* consists of th layers: an *external* tissue, an *internal* tissue, a a *middle* layer constituted of fibrous laminæ.

567. The tympanum in its usual state is not *tightly* stretched, and whenever an increase of tension is given to it hearing is for a time impaired. This may be shown in two ways; either by holding the breath, and then forcing air up the Eustachian tube so as to distend the drum *outwards;* or by exhausting the cavity, so that the superior pressure of the external air may force it *inwards.* The former of these distensions takes place when persons rapidly ascend into rarefied strata of air (78.); the latter occurs when they descend in diving-bells, where the air becomes condensed by the upward pressure of the water (80.).

When the drum of the ear is tightly stretched, *deep* sounds are scarcely audible, but very shrill ones are painfully acute.

Smoking through the ear.

568. Sometimes the drum of the ear is accidentally perforated, and then a person can cause the smoke of a pipe or cigar to *issue*

through it. The success of this achievement, however, always depends on the accidental perforation referred to, and is uselessly attempted if the tympanum of the ear be perfectly sound.

The smoke passes up the Eustachian tube which opens into the *pharynx**, and can, therefore, communicate circuitously with the mouth round by the uvula. Thus, in the subjoined woodcut,

Let N be the cavity of the nose,
E the opening of the Eustachian tube,
U the uvula,
P the palate of the mouth,
T the tongue.

Suppose the smoke to enter the mouth as the arrow, it can pass round by the uvula, enter E, and, if the drum of the ear be punctured, find its way out through the ear; if not, it must continue its course to N and come out through the nostrils.

569. The external ear is useful to reflect the sound-rays into the funnel. If too flat, hearing is

Folds of the ear.

* Pharynx, a muscular bag at the back of the mouth, which terminates in the gullet. Its use is to receive the masticated food before it is swallowed.

impaired, because the rays tumble out of the pavilion, instead of being reflected down the auditory passage.

The FOLDS are not without their function, inasmuch as they serve to entrap the passing sound-waves, and, being pretty good conductors of sound, to transmit to the tympanum the impressions they receive.

570. In horses, stags, rabbits, hares, cats, &c., the external part of the ear is considerably *prolonged*, and the sense of hearing in these animals is so acute, that they start at the stirring of a leaf.* The object of this acuteness is to put them on their guard at the approach of danger, and it is especially serviceable to beasts of chase.

Long ears.

Sometimes animals with long ears "prick them up," or bend them for-

* In these animals the little spiral channel situated in the inner ear, and technically called the *cochlea* (snail's shell), is unusually large. This, without doubt, is a main cause why the hearing of these animals is so acute.

ward, or turn them backwards, in order to listen more intently. By these means the cavity of their ears is turned in the direction of the sound which can more readily enter into the funnel.

571. BATS have very long ears to enable them to hear the feeble sounds of insects. As these animals search their prey in the dusk of evening, great acuteness of hearing is essential to enable them to find what would otherwise escape their observation. In order, however, that the noises which abound by day may not disturb their repose, they have the power of closing the external orifice of their ears by muscular action.

Bats.

572. The functions of the FUNNEL or meātus of the ear appear to be three-fold: (1.) To *concentrate the undulations*, like the tube of an ear-trumpet; (2.) to serve as *conductors of sound*; and (3.) to increase by *resonance* the force of the sound received.

Uses of the meātus.

573. Such is a general description

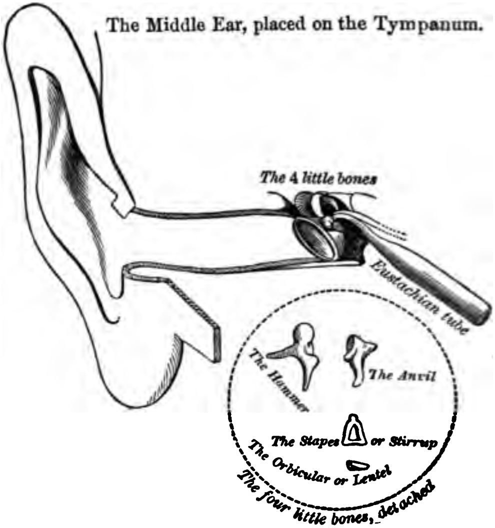
and such the uses of the "outer ear" —an apparatus not essential to audition, inasmuch as animals without this part of the organ, as whales, moles, birds, reptiles, and fishes, can nevertheless hear sounds with tolerable accuracy. Even the tympanum may be perforated or torn without destroying this useful sense; nay, those fishes which have no elastic membrane spread over the cavity of their ears hear through the interposition of the bones of their head; and sounds may be conveyed even to the human sensorium through the teeth, chest, skull-bone, or without any assistance of the external cartilage and its conduit. It must not, however, be hence inferred that the outer ear is useless; for, although the bare act of hearing can be effected without its aid, much that constitutes the delight and delicacy of the sense is inseparably connected with it.

Outer ear not essential

Sometimes the external orifice of the ear is

covered over with fine hair, to prevent the trance of dust and of other light bodies into passage.

§ 2. *The Middle Ear of the Hum Species.*



574. In contact with the tympanu is the MIDDLE EAR, which consists of

bony case closed on all sides, except at one single point towards the bottom, which opens into what is called the *Eustachian tube.*

575. This part of the apparatus of hearing is chiefly remarkable for a chain of *four little* bones, held together by fibrils. The office of this chain is to relax or tighten the tympanum, so as to adapt it to the force of the sound-waves which strike against it. It performs for the ear a similar service to that which the *iris* does for the eye, in adapting its aperture to the quantity of light which falls upon the cornea.*

Chain of four bones.

576. When sounds are very intense this chain of bones tightens the tympanum, in order to curtail the excursion of its vibrations; when, on the other hand, they are very feeble, the tympanum is somewhat relaxed, that

* The cornea is the whole visible part of the eye. The iris is the coloured circle which surrounds the pupil. The pupil is a little hole in the middle of the iris.

its vibrations may have more scope, and the nerve receive an appreciable shock.

577. The EUSTACHIAN* TUBE communicates with the mouth; hence, when persons listen very intently they *open their mouth*, that the sound-rays may enter their ears through the Eustachian tubes as well as by the ordinary conduits.

Eustachian tube.

578. The special office of the Eustachian tube is to supply the middle ear with air of the same density as that inhaled, and thus preserve in equilibrium the air on both sides of the tympanum. If this balance were not well adjusted the membrane would be strained by an unequal pressure, and hearing would be materially impaired (566.).

Another function of this tube is to convey away mucus secreted in the cavity of the tym-

* The Eustachian tube is so named after Bartholomew Eustachius, an Italian physician, who first discovered it. Eustachius died 1570, aged sixty-four.

, which would cause deafness, if suffered
ımlate.

9. Sometimes after bathing, or
a person has taken cold, Humming
ɔassage of the Eustachian in the ear.
is obstructed, and the air can-
irculate freely through it. When
is the case equilibrium can no
r be maintained, and a person is
sed of the derangement by a
nming or ringing in his ears."

0. Divers and aëronauts affirm
they hear from time to time Cracking
racking in their ears." This in the ear.
is occasioned by a sudden con-
ion of the muscle which serves to
the tympanum, and to accommo-
it to the increase of pressure either
within or from without.

pain in the ears felt by divers and
auts, *see* Nos. 78, 79, 80.

1. A "ringing in the ears" may
ɔroduced by laying a hot Ringing pro-
l over the external orifice, duced by a hot hand.
use the heat of the hand

rarefies the air in the funnel, and destroys the equilibrium.

582. If wax be suffered to accumulate in the ear a similar annoyance becomes often very distressing, because the thick viscous matter prevents the external air from reaching the tympanum, and preserves a partial vacuum between that membrane and the plug of wax.

From accumulated wax.

The same accumulation also impedes audition, because the sound-waves, instead of impinging against the drum of the ear, are buried in the cerūmen.

An accumulation of wax sometimes distresses the ear by its mere weight, and should then be removed by the aid of a syringe.

583. The middle ear is no more essential to the act of hearing than the external ear; for many animals possessed of this sense have neither the one nor the other of these parts of the auditory appartus. A very rudimentary organ suffices to make sounds audible; but there is as

Middle ear not essential.

much difference between mere audition and the perfect sense, as between the dull sight of the purblind and the acute vision of the quick-sighted.

Man may suffer the loss of all the *outer ear*, and of all the *middle ear*, except only one small bone called the *stapés*, or stirrup, without suffering the entire loss of hearing. This bone has an accidental use which renders its presence absolutely essential — it serves to cover a little hole called the *oval window*, which opens into the third or inner ear; if removed, the liquid contained in this cavity would run out, and complete incurable deafness instantly ensue.

Fishes have neither external nor middle ear, and yet have a sufficiently acute sense of hearing, as has been already shown (136.).

§ 3. *The Labyrinth or Inner Ear.*

584. The LABYRINTH or inner ear contains three compartments: the vestibule, the three semi-circular canals, and the cochlĕa or snail's-shell.

585. The VESTIBULE is a cavity of no regular shape, filled with a liquid re-

sembling water*, in which the roots of the acoustic nerve spread themselves

The Labyrinth or Inner Ear

(added to the other part).

and float. This may be called the *rudiment* of the ear, and it is the only part which exists invariably in all animals

* The membrane which lines the cavities of the labyrinth contains a colourless fluid technically called the *endolymph*, and is separated from the bony wall by a collection of liquid to which has been given the name of *perilymph*; so that it is suspended, as it

ssessed of an apparatus for hearing. ıus, in the crustăcea* and cephalo-da† the vestibule and nerve consti-te their entire organ. Osseous fishes ,ve, besides, the three simi-circular nals, and many reptiles a sort of iddle ear. The labyrinth of birds sembles that of reptiles, but their iddle ear is more fully developed. ıe mammalia possess all the complex ıchinery manifested in the ear of e human species, the only difference ing in the *wing* or external cartilage.

586. What office the *three semicir-lar canals* perform is wholly ıknown; some who love to eculate imagine they are useful to Semicircular canals.

re, in a liquid which bathes both its surfaces. The ·ve is plunged in the water which fills the vesti-le and is spread over the surface of the membrane.

* Crustacea are such animals as shell-fish, which ze no neck. They respire by the gills placed at sides of their body. Lobsters, crabs, cray-fish, ·imps, &c., belong to this order.

† Cephalopeda are a species of molluscs, such as tle-fish, whose organ of motion is situated round ir head.

enable us to ascertain the *direction* of sounds; but this is much more probably due to the *angle* at which the sound-rays strike upon the ear. Those which enter in a direct line pass straight on to the tympanum; whereas those which enter the auditory passage obliquely are reflected from side to side, and fall at last obliquely on the membrane.

The three planes of the semicircular canals are nearly at right angles to each other.

587. The power of distinguishing the *direction* both of sound and light is acquired only by long habit; it is some time before infants appear to know anything of the direction of noises which attract their attention. The idea of the *distance* of a sonorous body is another acquired perception, depending chiefly on the loudness or faintness of the sound. In this respect there is also a great similarity between the judgment of the eye and that of the ear. The eye judges of distance by

the distinctness and apparent size of known objects, and the ear determines the distance of sounding bodies by the distinctness and volume of the sound which reaches it.

588. That part of the inner ear called the *cochlea* or snail's shell is supposed by some physiologists to assist us in estimating the *pitch* of sounds; according to others, it enables us to entertain many sounds at once without confusion or distress, as when the multitude of sounds proceeding from a full band crowd simultaneously upon the ear. Cochlea.

Amphibious animals have no cochlea. In other reptiles it is very rudimentary, and in birds less perfect than in the mammalia.

589. The only part of the labyrinth or inner ear which is understood is the *vestibule*. The liquor which fills the cavity being agitated by the vibrations of the tympanum, air, and bones of the ear, shake the roots of the acoustic nerve; the motion is thence Vestibule.

communicated to the nerve itself, and the effect transmitted to the sensorium.*

590. Thus the *outer ear* collects the rays of sound, and reflects them down the auditory passage till they reach the tympanum or drum;

Office of each part.

The vibrations of the tympanum are communicated to the bones and air of the *middle chamber* of the apparatus;

These being put into reciprocal vibrations, shake the liquid contained in the *vestibule* of the "inner ear;" the agitation of the liquid is felt by the roots of the acoustic nerve, conveyed along the nerve itself, and ultimately produces the sensation of sound.

591. Although sound enters at the two ears we hear but one impression. Without doubt two impressions are made; but, as they are in perfect unison and very

Two ears render one sound.

* The sensorium is the seat of the five senses, almost universally supposed to be in the brain.

nearly simultaneous, the effect produced is simply an increase of intensity.

Much has been said by different writers upon single audition and single vision. Many have erroneously explained the phenomena by ascribing it to the union of the two nerves in one common point. It would be very easy to show the fallacy of this notion; but such a digression would be quite beside the object of this treatise.

Two sounds produce but one impression when they succeed each other in less time than the *twelfth of a second.* As the vibrations of any given sound which strike upon *one* ear reach the other also in less time than the *twelfth of a second* afterwards, the two make upon the sensorium but one impression. For the same reason the sound of *resonance* from walls, &c., makes but one impression with the *direct* sound. For the same reason also the ear is unable to appreciate the multitude of independent shocks which go to make up any given sound.

The same explanation, *mutatis mutandis,* may be applied to single vision.

SEC. II. SUMMARY.

592. The following summary may be interesting and useful to the reader:— Comparative ears.

1. In the HUMAN species the ear is most perfect.

It is so wonderfully constituted as to be able to appreciate a sound so grave that it proceeds from no more than two vibrations in a second, and another so acute, that it is the result of 70,000. It can listen to the tremendous crash of a peal of thunder, and yet discriminate the almost imperceptible shades of difference which constitute articulate language.

2. In other mammalia the external ear is in numerous instances prolonged.

3. In BIRDS the external ear wholly disappears, but all other parts remain, even the Eustachian tube.

Some birds have a tuft of feathers, like the *horned owl*, which serve the office of external ears. The cochlea of birds is very rudimentary, and loses the shape of a *snail's shell.*

4. In REPTILES the auditory passage or *meātus* disappears, and the drum is placed, like that of birds, at the external orifice. The *middle ear* also is generally simplified.

In serpents and some other inferior animals a small mass of chalk, called *otolith* (or ear-stone), floats in the liquid which fills the vestibule, and serves to intensify the undulations in much the same way as the pea occasionally shut up in a dog-call whistle.

In fishes these chalky crystals are sufficiently large, but are not so massive as in the ear of serpents.

In man and all the superior animals the ear-stones are pulverised and called *otoconia* (ear-powder).

N. B. Snails, lizards, tortoises, frogs, and toads have an apparatus for hearing which resembles that of birds. Crocodiles, so far from being *deaf*, as ancient tradition records, have ears as perfect as the highest order of reptiles, and even a sort of *external* ear.

5. In the *highest* order of FISHES the outer and middle ear wholly disappear, and only the reservoir of liquid with the three semicircular canals remain.

The *lowest* order of fishes have nothing of the apparatus except the cavity and its liquid.

The labyrinth of fishes is not of bone like that of the mammalia, but is simply a membranous reservoir filled with water, and con-

taining a certain number of minute particles of chalk.

Shads and one or two other fishes have a *chain of bones* resembling that which pertains to the middle ear of the human species.

6. In the MOLLUSCS* every part disappears except a vesicle situated on each side of the head, filled with water, in which float little solid corpuscles resembling the chalky crystals found in the ears of fishes.

Some mollusca have an apparatus somewhat more perfectly situated in their *antennæ* or horns.

7. INSECTS have no auditory apparatus, at least none like that of vertebrated animals; yet they appear sensible of sounds, especially those insects which chirp, hum, and buzz.

8. ZOOPHITES † have no apparatus

* Molluscs are animals, like the nautilus, whose body is soft, without any internal skeleton or articuculated covering.

† Zoophites are living creatures which in appearance resemble both animals and vegetables, as the star-fish, sea-hedgehog (*echinus*), &c.

for hearing, and exhibit no symptom whatsoever of sensibility to sound.

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593. We have now brought to a conclusion the interesting subject of "Sound and its Phenomena." We have treated of the cause, the qualities, and the conductors of sound, its rate of motion and the numerical value of its vibrations; we have examined the physical condition of numerous musical instruments and of acoustic tubes; we have searched into the mystery of echo and have explored the secrets of the voice and ear. Many wonderful things have passed in review before us, and many a trifle "light as air" has spoken trumpet-tongued of benevolence in design, of wisdom in contrivance, and of skill "past understanding" in execution. The penetration of philosophy has done something to unravel the "deep things of God," but what a Conclusion.

gordian knot of difficulties remains! What a tangled skein is yet before us! What a vast unknown is unexplored, which, haply, will never be made manifest till "this corruptible shall put on incorruption, this mortal immortality!" Nor can it be a matter of rational wonder that the ways of the Inscrutable are "past finding out," that the finite cannot compass the Infinite, that the works of the Eternal by searching grow more vast, by knowledge more astounding, by contemplation more inexplicable; that every mountain overpassed reveals new mountains in the distance, and every field explored leads onward to new fields of investigation, till we find ourselves in the predicament of the wise man of old who demanded at first *one* day to answer the question "What is God?" but, having thought upon the subject that one day, required two more; then a week, a month, a year; and still the longer he contemplated the further he

ɛemed from the object of his search. et the philosopher, who has meted ıe handiwork of Omnipotence with is rule a span long feel humbled at ıe littleness of his survey; let the rest ıke courage at what science has hitherto ɔhieved, and add a handful to the mass f human information.

ALPHABETICAL INDEX.

Reference is made to the paragraph numbers; *n* means note.

THE END.

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